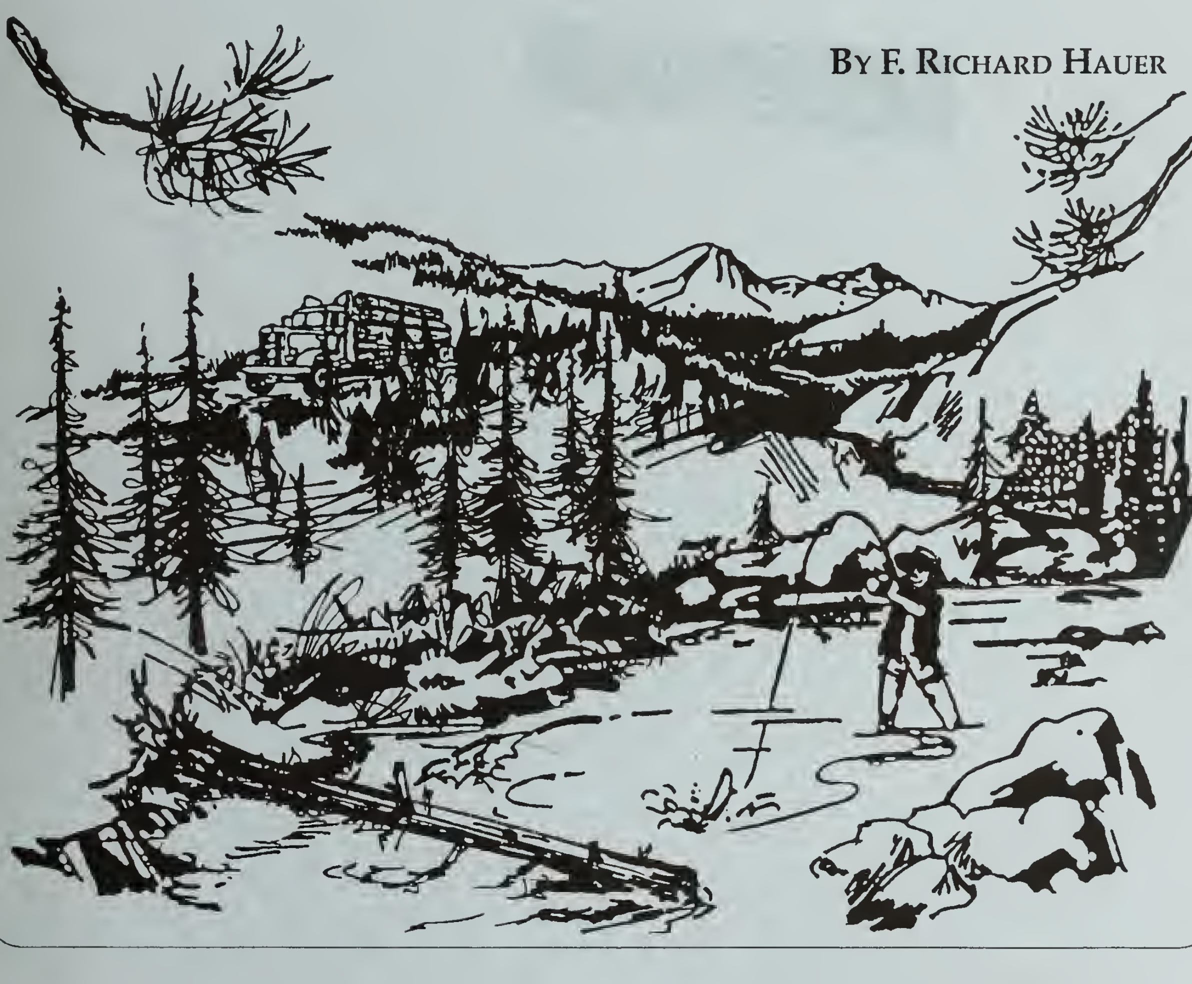
FLATHEAD BASIN FOREST PRACTICES
WATER QUALITY AND FISHERIES
COOPERATIVE PROGRAM

AN ANALYSIS OF THE EFFECT OF TIMBER HARVEST ON STREAMFLOW QUANTITY AND REGIME: AN EXAMINATION OF HISTORICAL RECORDS

BY F. RICHARD HAUER



JUNE 1991

About This Report

This report is one of ten individual studies conducted for the Flathead Basin Forest Practices/ Water Quality and Fisheries Cooperative Program. The Cooperative Program was administered by a Coordinating Team representing the Montana Department of State Lands Forestry Division, the Flathead National Forest, Plum Creek Timber Company, L.P., the Montana Department of Fish, Wildlife and Parks, the Montana Department of Health and Environmental Sciences' Water Quality Bureau, the University of Montana, and the Flathead Basin Commission.

The Cooperative Program's specific objectives were (1) to document, evaluate, and monitor whether forest practices affect water quality and fisheries within the Flathead Basin, and (2) if detrimental impacts exist, to establish a process to utilize this information to develop criteria and administrative procedures for protecting water quality and fisheries.

The ten individual studies included the evaluation of: (1) specific practices at the site level, (2) accumulation of practices at the watershed level, (3) general stream conditions, (4) water quality variables relative to levels of management activity in small watersheds, (5) fish habitat and abundance relative to stream variables influenced by forest practices at the watershed level, (6) long-term changes in large-stream dynamics related to historical records of natural and man-related disturbances, and (7) changes in lake sediments relative to historical records of natural and man-related disturbances. A *Final Report* was developed which contains summaries of each of the studies, a set of summary conclusions and recommendations, and a formal response to the recommendations by the land management organizations which administered the Cooperative Program.

Contributors

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Flathead Basin Forest Practices
Water Quality and Fisheries
Cooperative Program

An Analysis of the Effect of Timber Harvest on Streamflow Quantity and Regime: An Examination of Historical Records

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FLATHEAD BASIN
WATER QUALITY AND FISHERIES
COOPERATIVE

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EXECUTIVE SUMMARY

The Flathead Basin Water Quality and Fisheries Cooperative charged the author with the responsibility to determine whether there is any evidence that timber management practices have altered natural streamflows based upon data contained within the historical record of mean daily stream discharge.

Streamflow, precipitation, temperature and snow pack data were obtained through the state Natural Resource Information System, Helena MT. Data concerning timber harvest quantity, location and type were obtained from the Flathead National Forest, Department of State Lands, and Plum Creek Timber Co. Historical fire records were obtained from the Flathead National Forest and Glacier National Park.

Streamflow quantity and regime from 22 gauging sites in the Flathead Basin were analyzed for changes that may be attributed to timber harvest. Analyses were conducted in light of natural interannual variabilities of climate, past fire history, and current logging practices. Focus was directed toward determining possible changes in 4 components of annual streamflow: 1) discharge response to specific rainfall events that are distinct and separate from influence of stored water as snow pack, 2) spring runoff quantity or regime (e.g. height, breadth, or temporal sequence of hydrograph), 3) annual discharge to annual precipitation relationships, and 4) the relationship of annual maximum and annual minimum discharge. This report does not attempt to detail every analysis that was conducted. Many of the comparative statistics that were run, particularly on untransformed data (ie. data which did not account for interannual variability in temperature, precipitation or snow pack), were insignificant due to high variability. Furthermore, some of the databases, particularly streamflow on very small creeks, spanned relatively short time periods, typically 3 years, which did not permit long term comparative analyses.

Results of the analyses revealed several interesting changes in streamflow relationships that may be attributed to timber harvest due to conformity with hypotheses and timber harvest trends.

1) It was determined that the rising limb of the spring runoff hydrograph is primarily driven by temperature and that the volume of runoff is closely correlated with annual snow pack. When these factors are accounted for by comparing years of similar temperature regimes and transforming the discharge data based on available snow pack, it appears that streams are accumulating discharge volumes earlier in the runoff period since experiencing increased logging when compared to the timing of runoff prior to logging.

2) Comparison of long term trends of annual Qmax and annual Qmin (ie. maximum vs. minimum discharge) it appears that the Middle Fork of the Flathead River, which has experienced relative little logging, is becoming increasingly stable in its Qmax:Qmin relationship while the North Fork, which has had significantly more timber harvest, is becoming decreasingly stable in its Qmax:Qmin relationship. In other words, the North Fork is becoming more "flashy" in its discharge while the Middle Fork is becoming less "flashy". This is particularly significant in light of the decrease in fires in both drainages, which presumably would contribute to less flashy conditions in both watersheds. Thus, the Middle Fork, which had similar area to that of the North Fork involved in forest fires prior to the advent of broad scale fire prevention (ie. since the 1930's), has been progressing to increased discharge stability, while the North Fork has decreased in discharge stability since the advent of extensive logging.

3) Although the analyses conducted within the auspices of this study provide some insight into the effects of timber harvest on streamflow its affectiveness is somewhat limited by the paucity of data among smaller watersheds. Most of the long term databases of streamflow in the Flathead Basin are restricted to the large 4 - 6 order streams and rivers. However, it is the lower order watersheds that are likely to respond most dramatically and quickly to alteration of the landscape. Thus, it would be in the best interest of large land holders and their managers to commit to development of a long term database on a series of benchmark streams to assess long term effects of timber management on the physical, chemical and biological variables of stream ecosystem structure and function.

INTRODUCTION

BACKGROUND

In northwestern Montana, rhithron streams originate mainly from snow pack within high elevation, headwater areas or from groundwater springbrooks at lower elevation in the valleys. Typically, these streams drain watersheds forested by mixtures of lodgepole pine (*Pinus contorta*), Ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), Engelman spruce (*Picea engelmannii*), and western larch (*Larix occidentalis*), as well as other predominantly coniferous species. For well over a century these forests have been utilized for timber supply. However, not until after the late 1940s and early 50s were large tracts of timber cut from the extensive non-private forest lands.

Recently in the Flathead River Basin and elsewhere in Montana, the National Forest Service, Department of State Lands, and large private land holders, such as Plum Creek, have come under increasing public scrutiny with speculation that timber removal, particularly clear-cutting of large tracts, may significantly alter aquatic resources. Resident lotic communities, as well as transient populations of adfluvial fishes, may be significantly impacted by changes in stream ecosystem structure and function. Physical and biotic changes on the landscape may have profound effect upon the physico-chemistry and biology of a stream draining the disturbed watershed. Timber harvest may affect transport and deposition of inorganic sediments, stream temperature, water chemistries including nutrient loadings, as well as many other factors. Critically important components of stream ecosystem integrity and water quality are streamflow quantity and regime, which also may be affected by deforestation.

Present knowledge of streamflow changes resulting from logging within specific watersheds is based primarily on experiments usually conducted on small catchments of less than 0.75 - 1 mi^2 (2 - 2.5 km^2) (Hibbert 1967, Bosch and Hewlett 1982). Consequently,

there is very little published literature dealing specifically with effects of timber harvest on the discharge of higher order streams, especially streams flowing from large drainage basins, which may respond differently than small watersheds. Although most recently some experiments have been conducted on watersheds larger than 4mi^2 (~10 km^2, Cheng 1989), most studies of changes in streamflow in relation to temporary deforestation (e.g. timber harvest, insect damage, fire) within such larger areas have been in relation to fire or insect epidemics (Bethlamy 1974, Cheng 1980, Potts 1984), and except for studies by Cheng and Potts which deal with monthly water yields, most studies examine changes on an annual basis. Inspite of the importance of water yield to stream quality, I know of only one other study examining long term databases from large watersheds (>40 mi^2, ~100 km^2) in relation to deforestation or any other large alterations of the landscape (Bartos 1989).

The purpose of this study was to examine the long-term, historical records of stream discharge (at USGS sites), daily precipitation, daily temperature (at NOAA sites), and annual snow pack (at USFS sites) and attempt to determine if there has been a significant change in either streamflow quantity or regime in relation to timber harvest, particularly over the past 30 years.

DATABASES

Long-term databases of stream discharge exist for several stream and river gauges in the upper Flathead River Basin, which are maintained and operated by the U.S. Geological Survey. These databases are of different time durations with some going back to near the turn of the century, while others are for short time periods of only a few years (Table 1). Daily temperature and precipitation records are available for four locations in the upper Flathead Basin, Kalispell, Bigfork, Hungry Horse and West Glacier. Numerous locations around the Flathead Basin are monitored for annual snow pack.

Table 1. Stream and river sites with discharge records including the years of available data.

Mainstream River Sites	Duration of Record
North Fork at US - Canadian border	1929 - current
North Fork near Columbia Falls	1910 - current
Middle Fork near west Glacier	1910 - current
South Fork near Columbia Falls	1910 - 1954
South Fork below Hungry Horse Dam	1965 - current
South Fork at Spotted Bear	1948 - 1967
Mainstem Flathead River near Columbia Falls	1922 - current
Swan River at Bigfork	1922 - current
Stillwater River near Whitefish	1931 - current
Whitefish River near Kalispell	1922 - current
Smaller River and Creek Sites	
Swan River at Condon	1973 - current
Stillwater River at Olney	1973 - 1982
Spotted Bear River	1949 - 1956
Canyon Creek	1965 - 1967
Emery Creek	1965 - 1967
Goldie Creek	1965 - 1967
Graves Creek	1948 - 1967
Hungry Horse Creek	1969 - 1972
Soldier Creek	1965 - 1967
Sullivan Creek	1949 - 1977
Swift Creek	1973 - 1982
Wounded Buck Creek	1965 - 1967

Timber harvest records were available through the Flathead National Forest, Department of State Lands and Plum Creek. There are no detailed records available for small, private timber harvests. Much of these data were not computerized and thus not easily accessible, with the exception of National Forest lands and to a lesser extent State Lands. Historical fire records were obtained through the Flathead National Forest and Glacier National Park.

The discharge, precipitation, annual snow survey, timber harvest and fire data are available as both MS-DOS text files and Apple Macintosh text files attached as Appendices with the Archived Copy of this report. This archived copy is maintained in the library archives of the Flathead Basin Commission.

DATA ANALYSIS

The objectives of this study were very specific; to determine changes, if any, in streamflow quantity or regime in relation to timber harvest. Examination of these databases was focused toward resolving four areas or questions: 1) During base flow conditions that prevail in autumn (September 1 to November 30), has there been a change in the streamflow quantity or regime in response to large precipitation events that result in minor flooding (ie. discharge increase of >3x)? 2) During spring runoff (April 1 to June 30) has there been a change in discharge volume, maximum streamflow, duration of high discharge, or temporal periodicity of discharge? 3) Has there been a change in the relationship of annual precipitation and annual total discharge from a watershed that might be related to timber harvest? and 4) Has there been a change in streamflow maximum/minimum relationship through time suggesting an increase or decrease in stream "flashiness"?

Evaluation of available data indicated that very long term discharge records only exist at a few sites around the Flathead Basin. Furthermore, these sites are located on large 4^{th} - 6^{th} order rivers draining large land areas (Table 1). For example, the river gauge on the North Fork is located below 1,548 mi^2 (4,009 km^2) of watershed, the Middle Fork river gauge 1,128 mi^2 (2,922 km^2) and the Swan

River at Bigfork 671 mi^2 (1,738 km^2). Consequently, it was necessary to examine streamflow data in relation to broad annual variabilities in climate, as well as major landscape changes through time. Some of the analyses used in this study are not standard techniques employed by hydrogeologists, primarily because the size of the watersheds and interannual variabilities make direct comparisons within and between watershed and from year to year untenable.

A very broad spectrum of analyses were conducted on the data. Generally, the data from smaller creeks, which have the greatest potential of revealing changes in streamflow, were of too short a time duration or had inadequate supporting data (e.g. watershed specific precipitation, temperature, snow pack) to escape the inherent problem of interannual variation. Therefore, what are presented herein are those analyses which come from temporally extensive databases that could be analyzed for long term trends as well as those analyses which were deemed tractable due to low interannual variances. Much of these analyses involve examination of runoff patterns in response to specific climatological driving forces, such as spring temperature trends, spring snow pack, and autumnal precipitation.

DESCRIPTIVE RESULTS

RECENT FIRE HISTORY

Wildfire has been an important part of the natural landscape of the northern Rocky Mountains at least since the recent Pleistocene. Fires during the late 1800s and early portions of this century burned extensive acreages throughout the Flathead River Basin. However, active fire suppression since the 1920's and 30's has been very effective in reducing the size of individual fires and the extent of fires within a specific fire season (Fig. 1). The relevance of fire to this study is through the comparative role of natural, temporary deforestation from fire verses that due to timber harvest.

Figure 1. Occurrence of large fire in the Flathead Basin from 1880 to present.
(A) Total acres within each of the major drainages.
(B) Total acres burned by decade.

Total area burned in the North Fork, Middle Fork, and South Fork during the past 100 years total nearly 1.4 million acres (~600 thousand hectares); however, less than 3% of that has occurred during the last 50 years. Most of the fires occurred during particularly pronounced years, such as 1910 when there were major fires across much of the northwest and over 800,000 acres (>325,000 ha) burned in the Flathead Basin alone (Fig 2).

TIMBER MANAGEMENT

Timber harvest records were obtained from the Flathead National Forest, Department of State Lands and Plum Creek for the drainages of the North Fork of the Flathead River, the Swan River and Swift and Lazy Creeks.

The timber harvest records from the North Fork reveal a steady increase in timber sales on National Forest lands beginning in the early 1950's and continuing until the early 1980's with a general decline during the past 8 years (Fig. 3A). State Lands' timber harvest, by contrast, is more punctuated with periodic sales. Logging activity in British Columbia was particularly intense during the 1980's. An examination of the ten year accumulated harvest illustrates how timber harvest accumulates such that on any one year relatively large areas have been cut within the recent past with potential streamflow effects (Fig. 3B). Because of wide time variability in timber regrowth, there is no standard time over which an area is considered affected by harvest; therefore, a period of ten years was selected as an approximate time appropriate for the Flathead Basin. Although admittedly, this was not based on any emperical data.

Examination of timber harvest in the Swan River drainage indicates steady growth of timber harvest on Flathead National Forest Lands during the 1950's and early 60's with a relatively stable harvest throughout the 1970's and 80's with some interannual variation. However, State Lands harvest was maximized during the early 1970's, followed by a decline. This was replaced by extensive

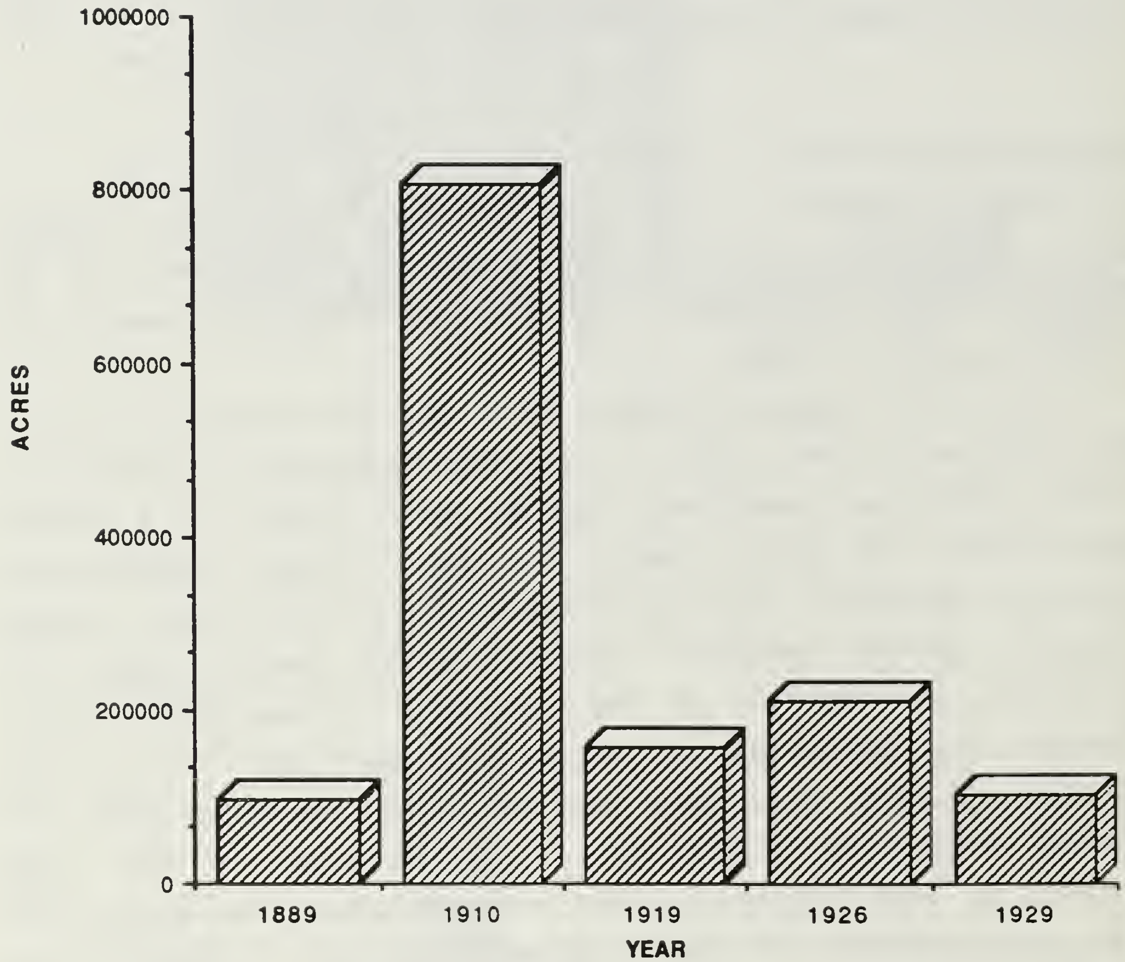


Figure 2. Total acres in the Flathead Basin contained within a large fire perimeter on those years of major fires.

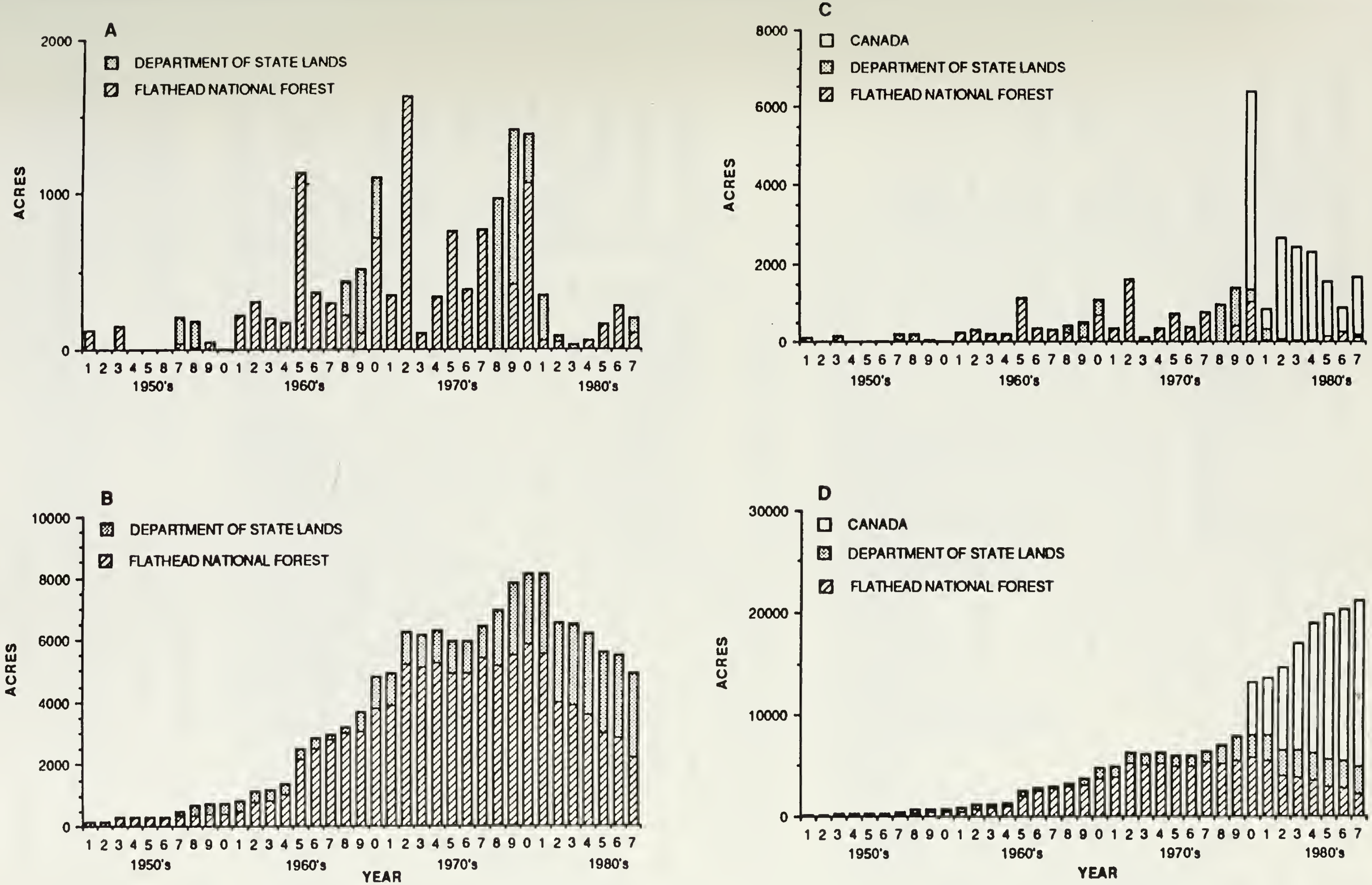


Figure 3. (A) Total equivalent clear-cut acres (ECA) harvested for each year from 1950 through 1987 in the North Fork drainage.
(B) Ten year cummulative ECA harvested on FNF and DSL lands in the North Fork drainage.
(C) Total ECA harvested in the North Fork drainage on FNF, DSL and British Columbia lands.
(D) Ten year cummulative ECA harvested on FNF, DSL and British Columbia lands.

cutting on Plum Creek lands such that in the mid 1980's nearly 5000 equivalent clear-cut acres (ECA) were cut annually (Fig. 4A). This is reflected in the 10 year accumulated harvest record which illustrates that in the late 1980's nearly 30,000 ECA were cut within the recent past with potential affect on streamflows (Fig. 4B). In Swift Creek drainage above Whitefish Lake there has been a relatively steady harvest pressure on the forest, with the exception of harvest of spruce, primarily in response to insect infestation in the 1950's (Schultz, pers. comm; Fig. 5A). Since 1975, Plum Creek has increased timber harvest in this area and by 1988 comprised over 50% of the timber land harvested within the last 10 years (Fig. 5B). These three drainages, the North Fork, Swan River and Swift Creek have had a total harvest based on the available data of 31107, 58938, and 11201 ECA since 1950, respectively.

ANNUAL DISCHARGE, TEMPERATURE, SNOW PACK, AND PRECIPITATION PATTERNS

The annual pattern of streamflow in Flathead Basin streams, and rivers is primarily driven by the spring melting of winter snows. The spring runoff discharge is typically an order of magnitude greater than mean low flow. As can be seen from the illustration of the mean annual discharge by decade in the North Fork from the1950's through the 1980's, peak streamflow occurs at approximately day 250 of the Water Year, or in other words, usually around May 18 (Fig. 6). However, there is considerable interannual variation in the total volume of discharge, the maximum discharge and exact timing of that discharge. This can be easily seen in the figures given in Appendices A and B, which illustrate the mean daily discharge of the North Fork (A) and Middle Fork (B) for the runoff period (April 1 through June 30) of each year from 1940 through 1986.

The annual temperature pattern is typical of temperate regions of the world, with summer temperatures ranging from >80 to ~50 °F and winter temperatures from -40 to 40 °F (Fig. 7). The Flathead Basin is generally dominated by Pacific Maritime storm tracks.

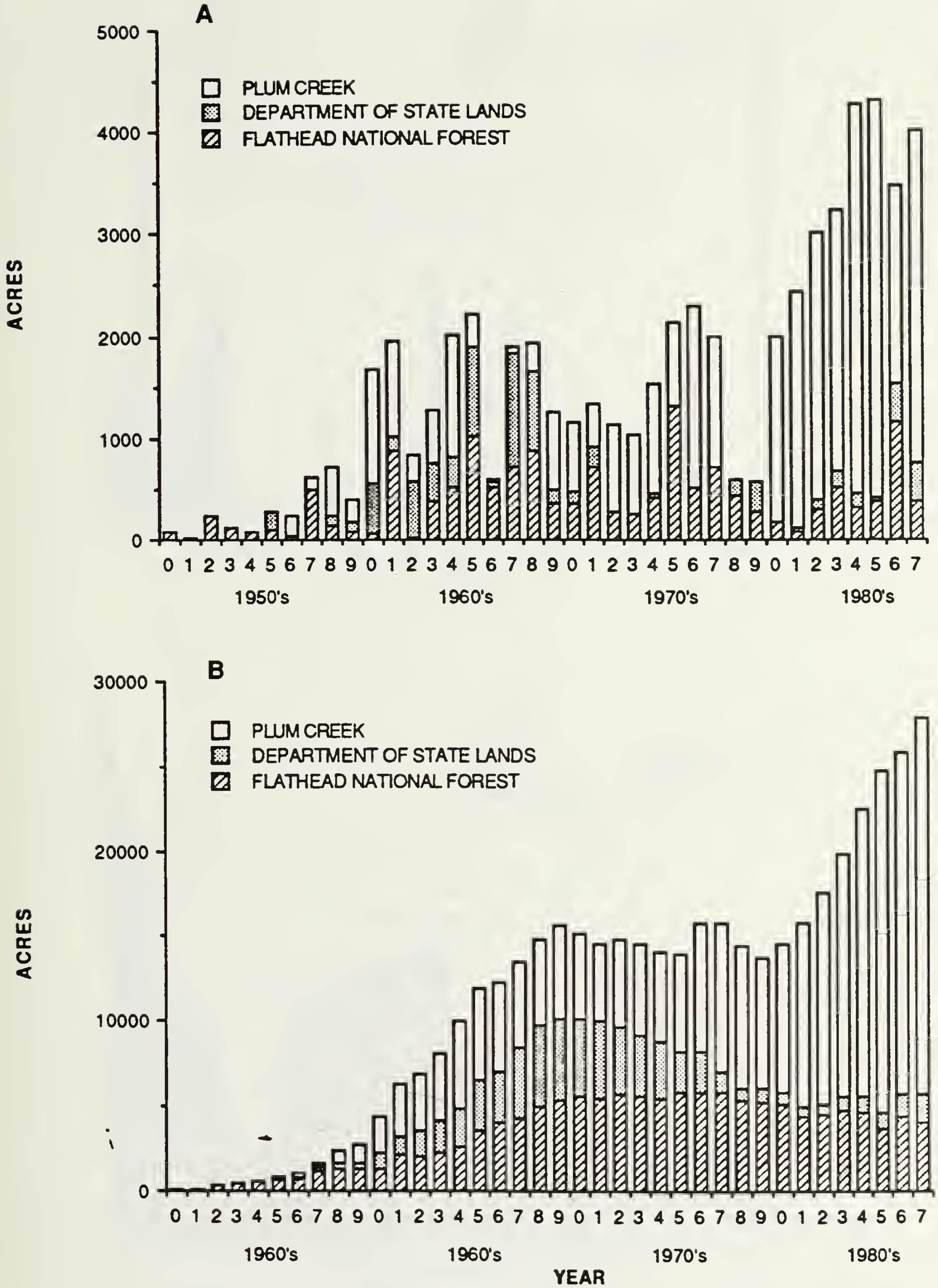


Figure 4. (A) Total equivalent clear-cut acres (ECA) harvested for each year from 1950 through 1987 in the Swan River drainage.
(B) Ten year cummulative ECA harvested by land owner in the Swan River drainage.

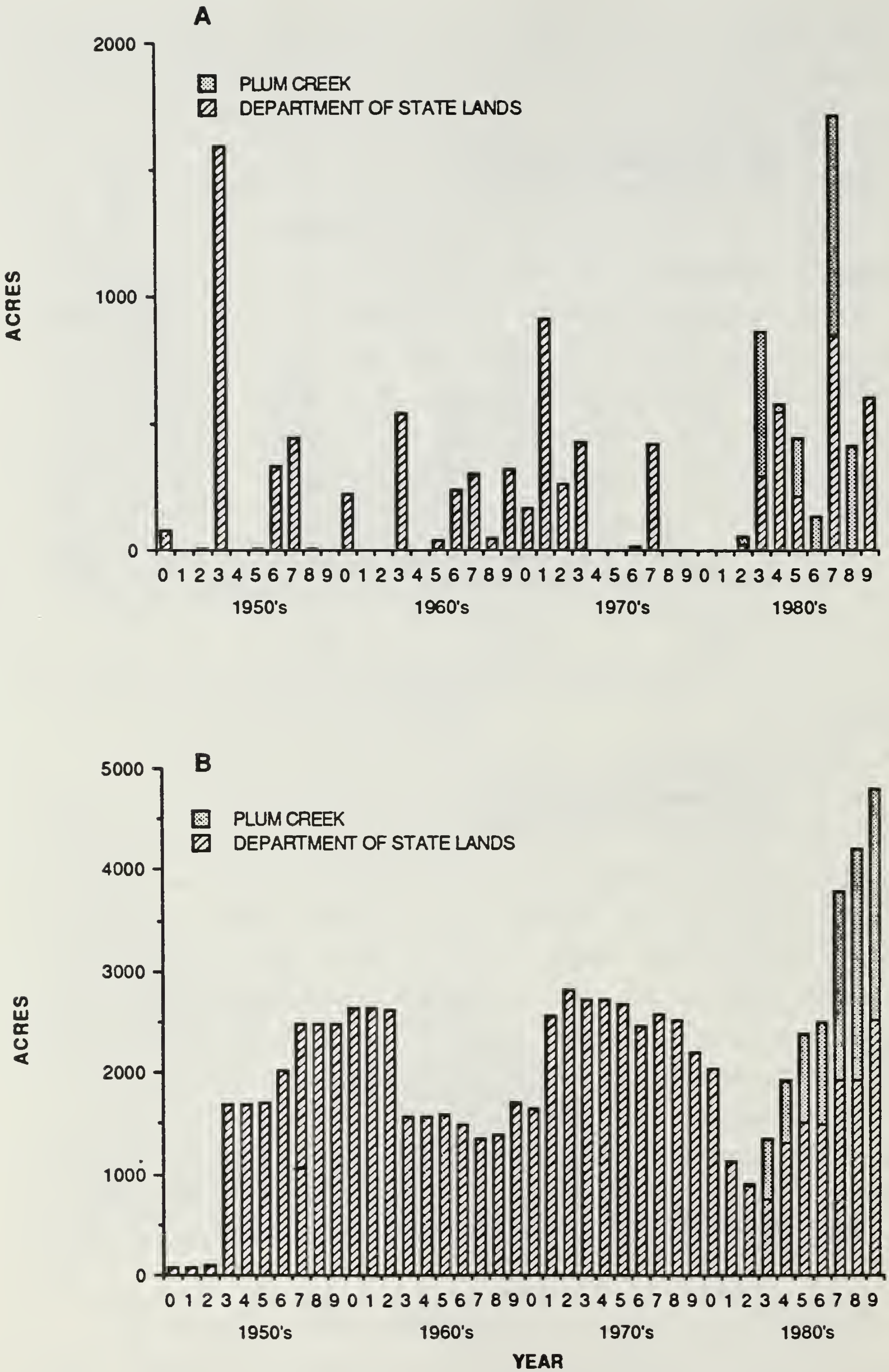


Figure 5. (A) Total equivalent clear-cut acres (ECA) harvested for each year from 1950 through 1987 in the Swift Creek drainage.
(B) Ten year cummulative ECA harvested by land owner in the Swift Creek drainage.

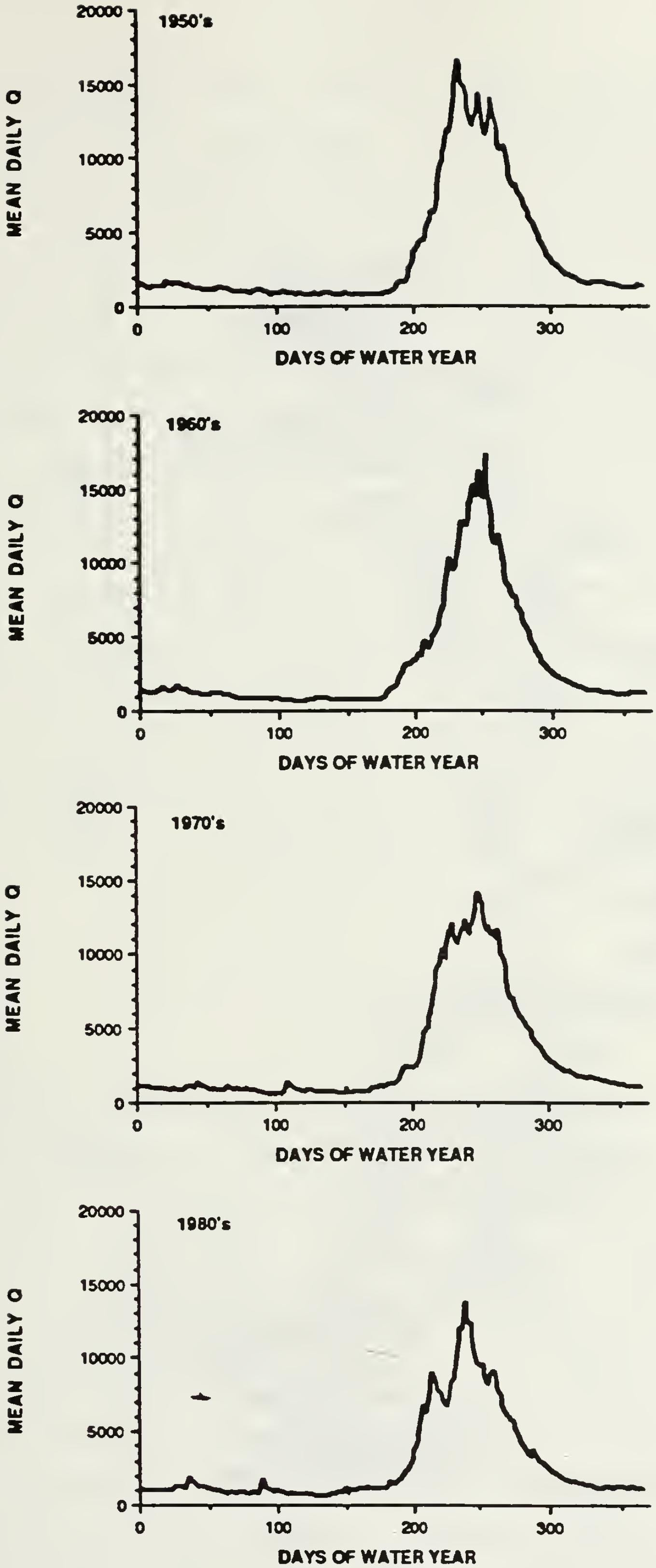


Figure 6. Average mean daily discharge by decade for the 1950's through the 1980's, illustrating the dominance of the spring runoff on the annual hydrograph for the North Fork of the Flathead River.

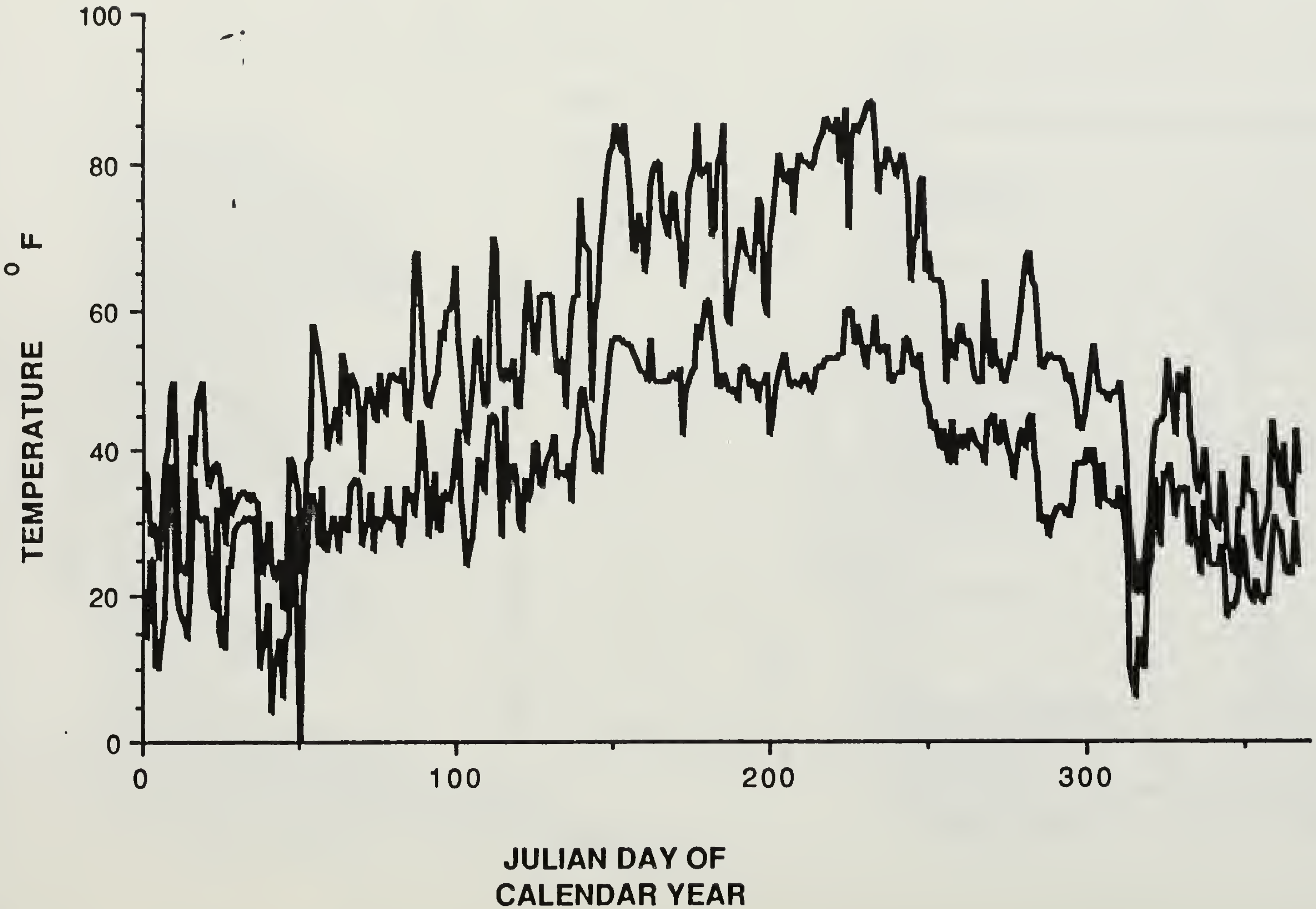


Figure 7. Maximum and minimum daily temperatures (°F) at West Glacier in 1986, illustrating the general temperature trends in the Flathead Basin.

Periodically during winter, very cold continental air masses will dominate the east slope of the northern Rocky Mountains and spill westward into the valleys of the Flathead Basin. During the critical spring warming period daily temperatures fluctuate significantly in conjunction with high and low fronts moving eastward from the Pacific coast (Fig. 8). In this illustration one can observe the sequentially fluctuating daily maximum temperatures from April through June in two typical years. Note the general warming trends that are interrupted by cold weather fronts that track through the basin. Daily precipitation was reasonably well correlated with decreasing temperatures as can be observed from the daily rainfall records on the same years as illustrated in Figure 8. However, volume of precipitation was not predictable from one storm front to another (Fig. 9). Snow pack at the end of the winter period (ie. April 1 each year) available for spring runoff was highly variable between years. Values of water equivalent snow pack (swe) ranged from ~7 to 27 inches (Fig. 10).

ANALYSES

AUTUMNAL DISCHARGE AND PRECIPITATION

Examination of autumnal streamflow in the North and Middle Forks for the period of record revealed eleven years which experienced a flooding event (increased discharge >3-4X average autumnal streamflow) during the period from September 1 to November 30. However, it was determined that there was poor correlation between precipitation volume (recorded at Kalispell prior to 1950 and/or at West Glacier after 1950) and either the timing or extent of increased streamflow. These relationships are illustrated in Figures 11 - 16 show individual precipitation events each year of an autumnal flooding event and corresponding increased stream discharge. As can be readily seen, for example in 1914, there was a significant rainfall extending over a 5 day period with as much as 1.4 inches of precipitation on one day; however, there was no

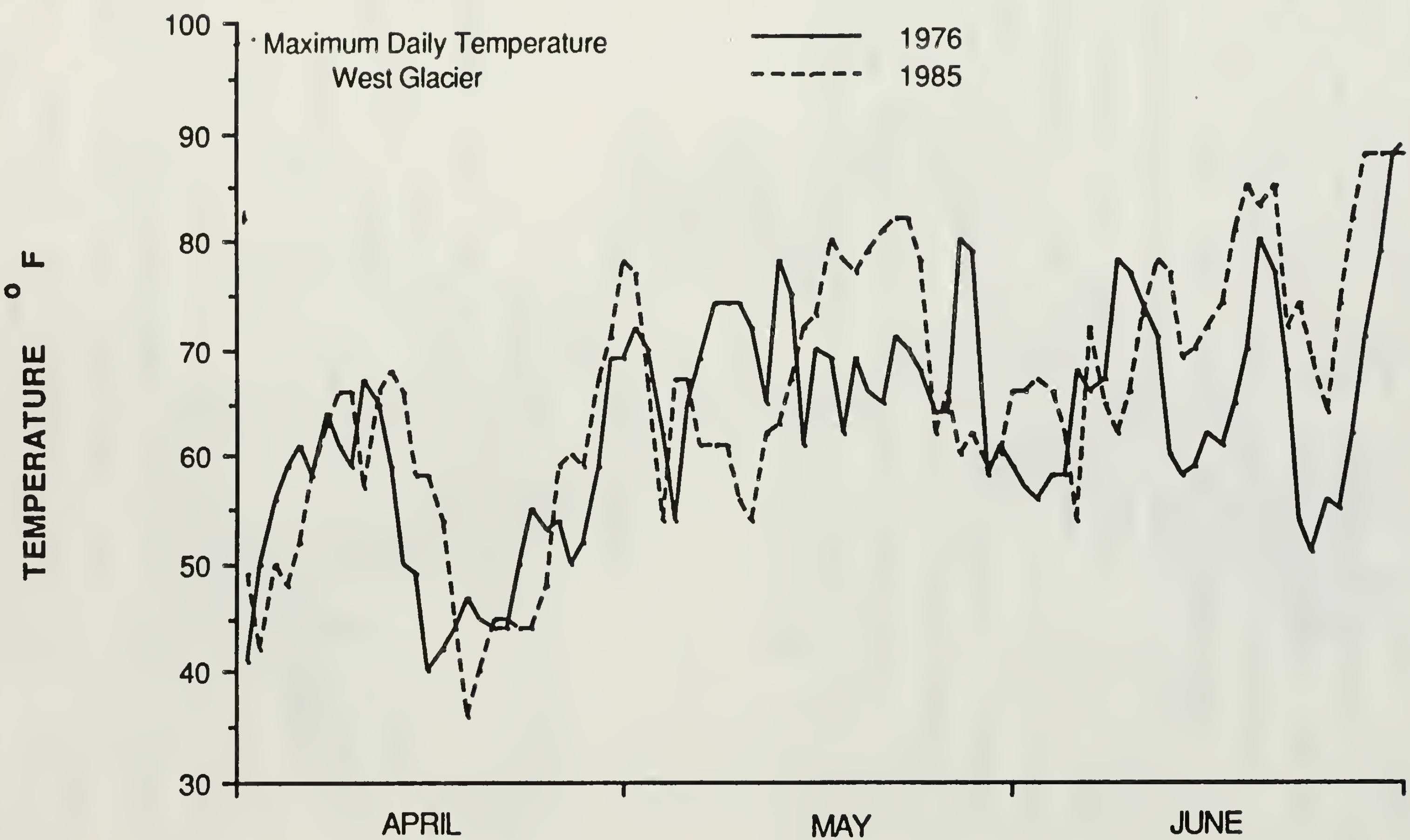


Figure 8. Maximum daily temperature (°F) during the period from April 1 through June 30 at West Glacier in 1976 and 1985, illustrating the interannual variability of temperature regimes within generalized warming trends of spring runoff.

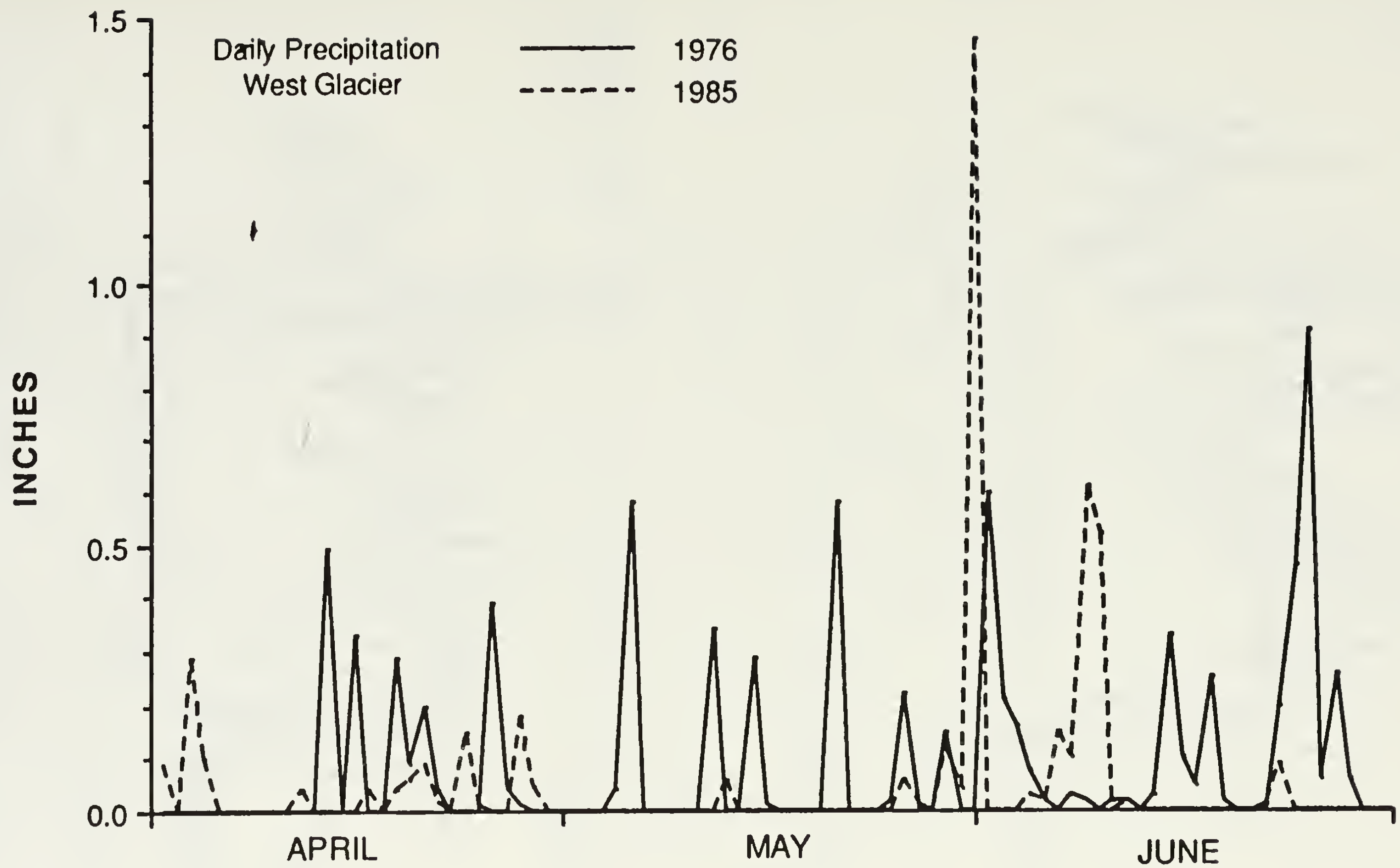
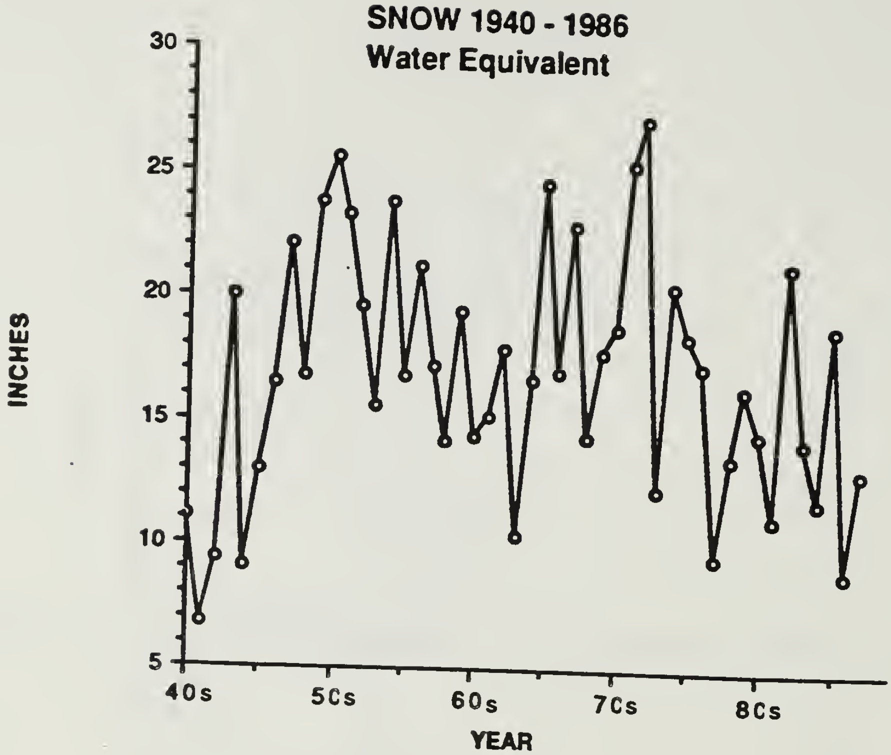


Figure 9. Daily precipitation (inches) during the period from April 1 through June 30 at West Glacier in 1976 and 1985, illustrating the interannual variability of precipitation regimes during the spring runoff.



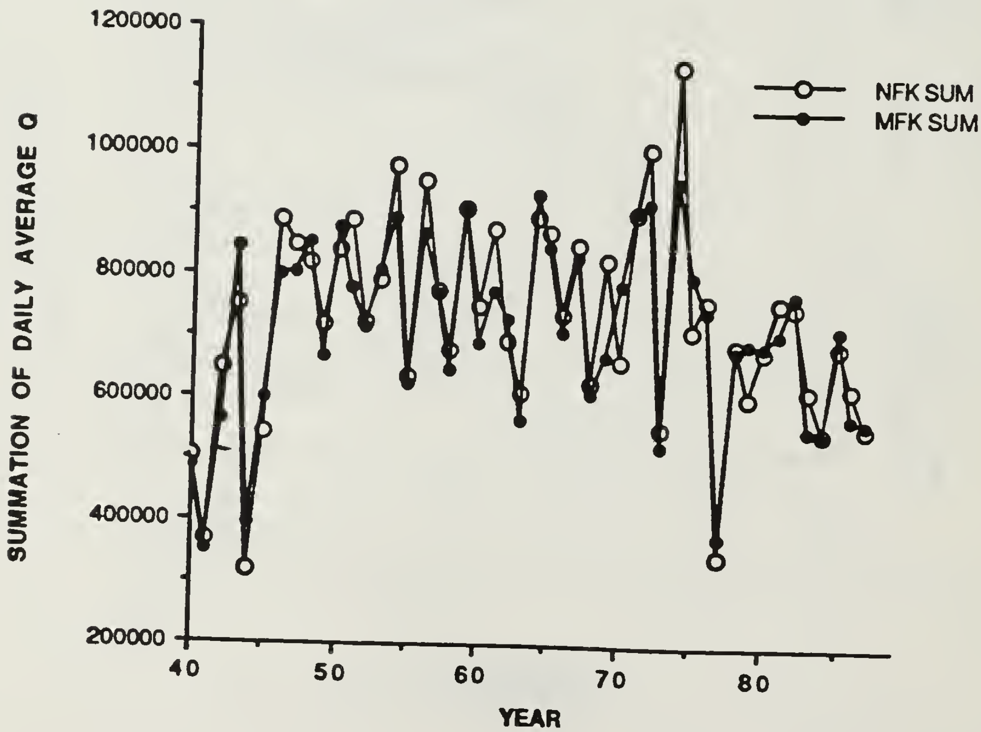


Figure 10. Mean snow water equivalence (swe) at Marias Pass and Desert Mountain on April 1 of each year from 1940 through 1987 and the summation of mean daily discharge (Q) in the North and Middle Forks of the Flathead River for the same time period.

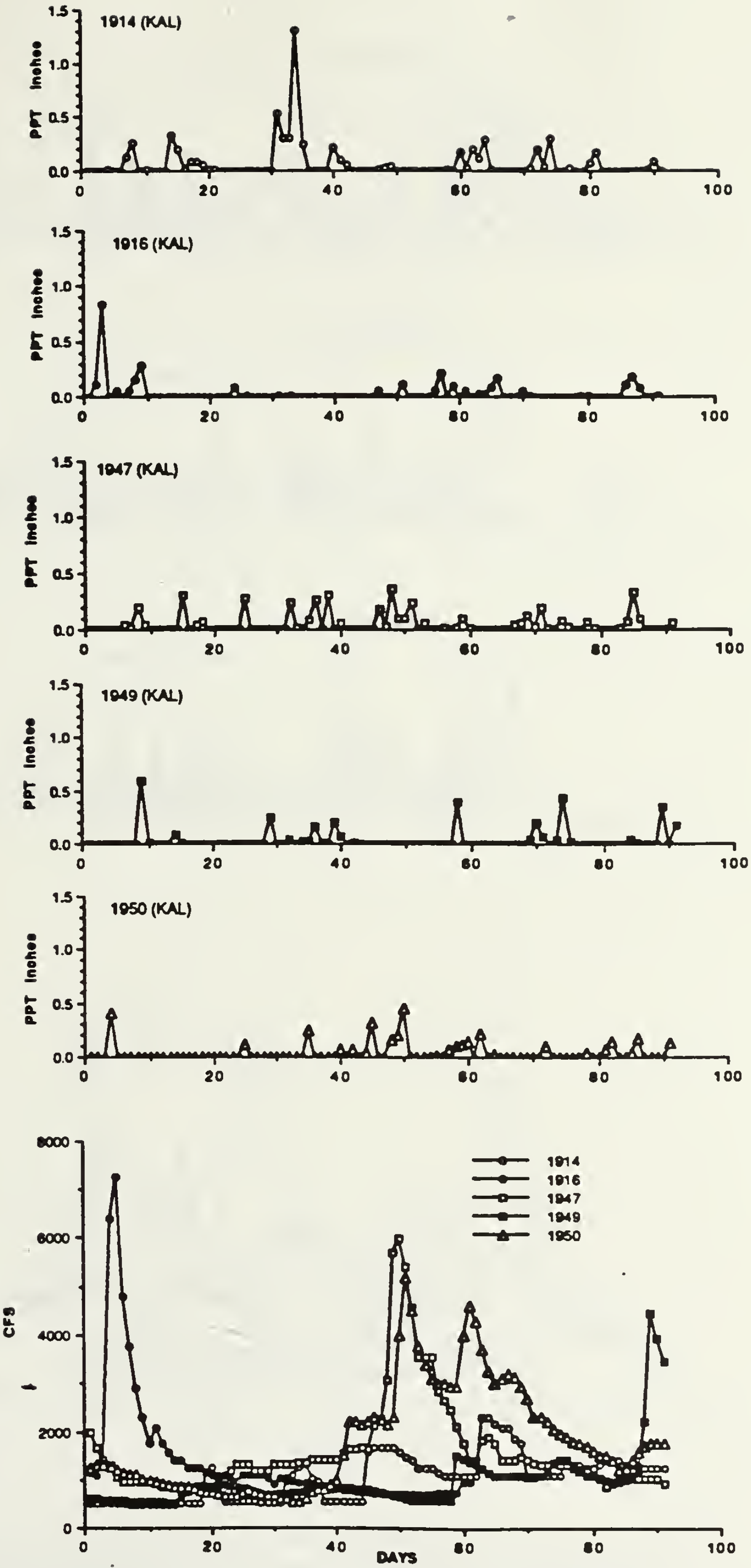


Figure 11. Precipitation and corresponding discharge in the North Fork of the Flathead River on years with an autumnal flooding event (ie. >3x the long term mean autumnal flow) from 1914 through 1950. Time expressed as days from September 1 through November 30.

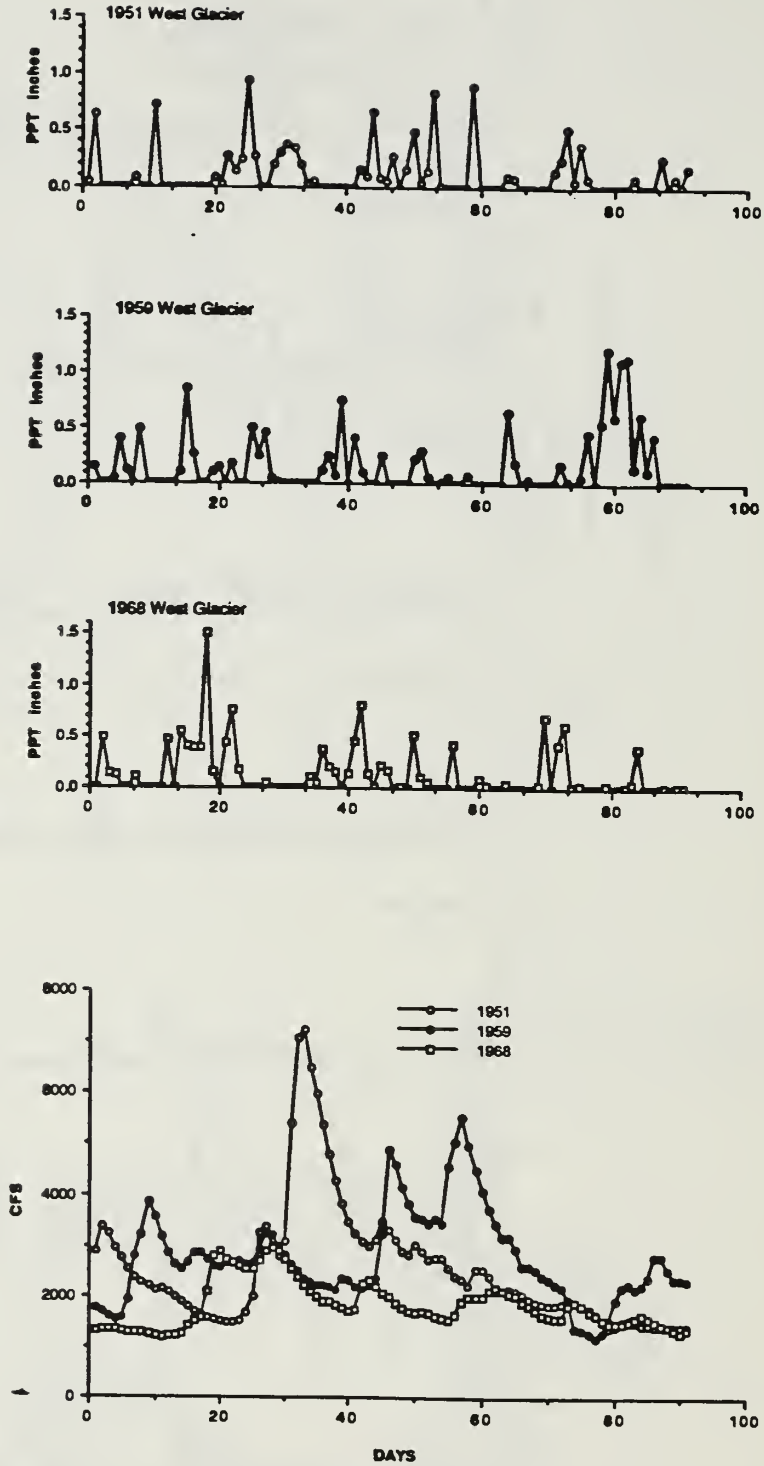


Figure 12. Precipitation and corresponding discharge in the North Fork of the Flathead River on years with an autumnal flooding event (ie. >3x the long term mean autumnal flow) from 1951 through 1970. Time expressed as days from September 1 through November 30.

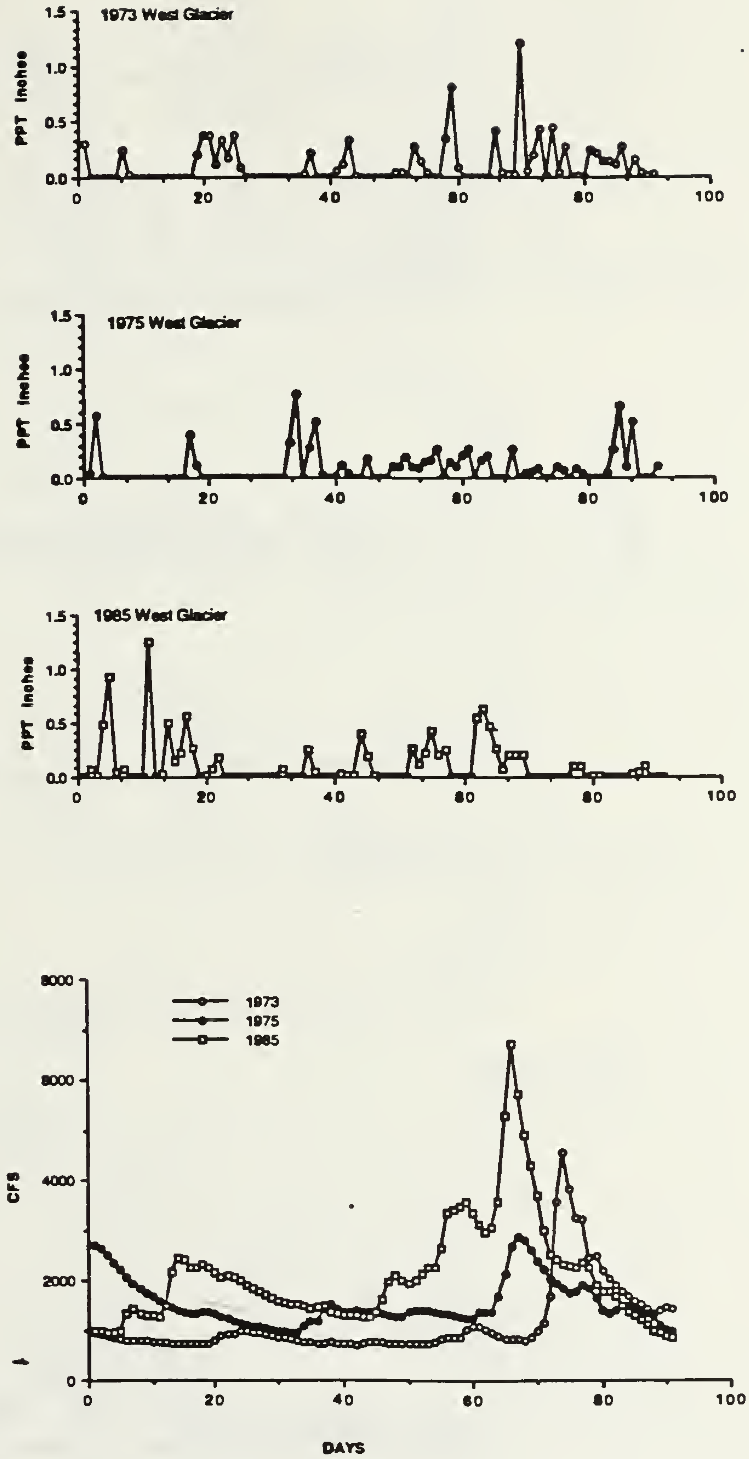


Figure 13. Precipitation and corresponding discharge in the North Fork of the Flathead River on years with an autumnal flooding event (ie. >3x the long term mean autumnal flow) from 1971 through 1986. Time expressed as days from September 1 through November 30.

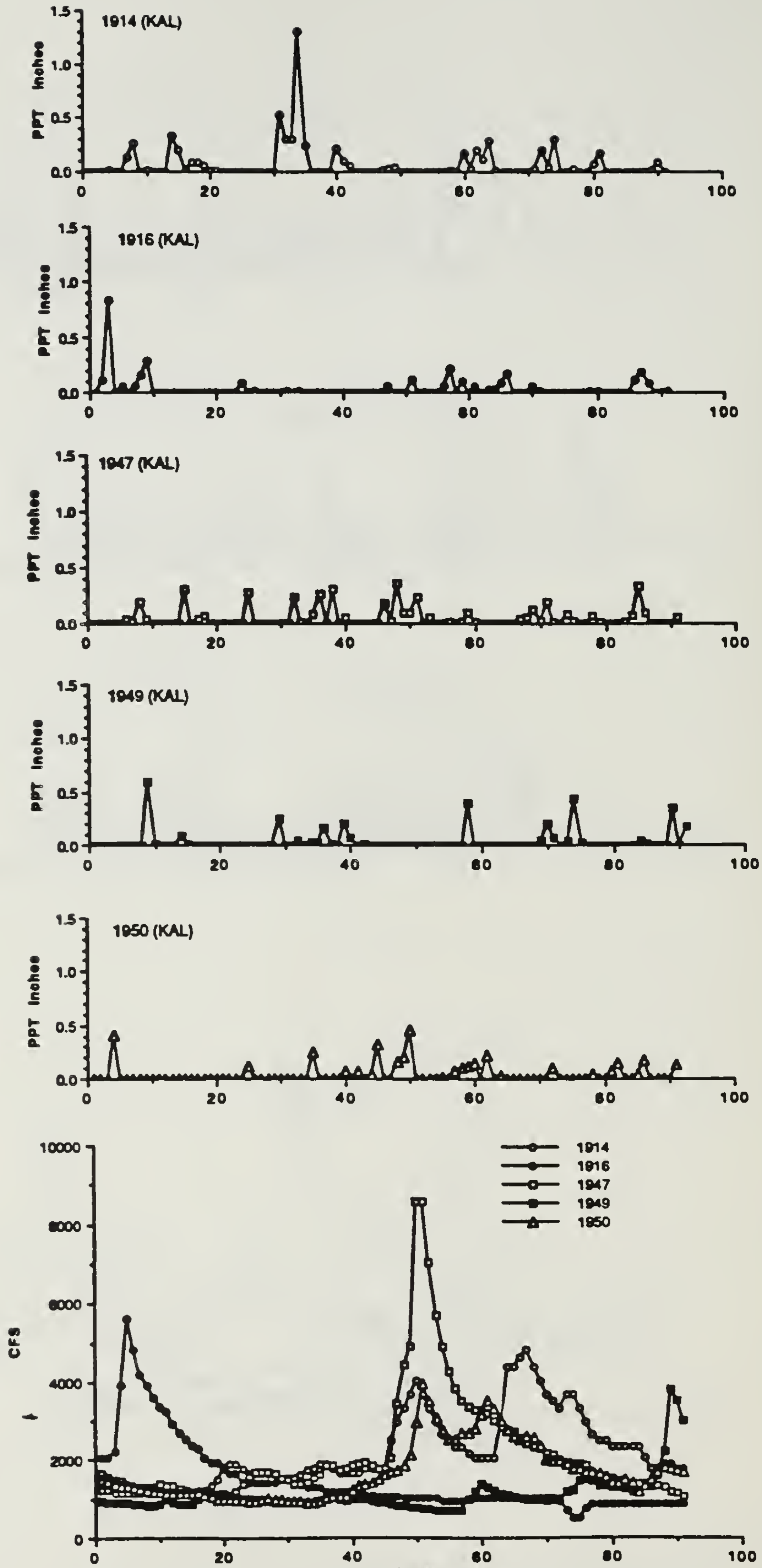


Figure 14. Precipitation and corresponding discharge in the Middle Fork of the Flathead River on years with an autumnal floodin event (ie. >3x the long term mean autumnal flow) from 1914 through 1950. Time expressed as days from September 1 through November 30.

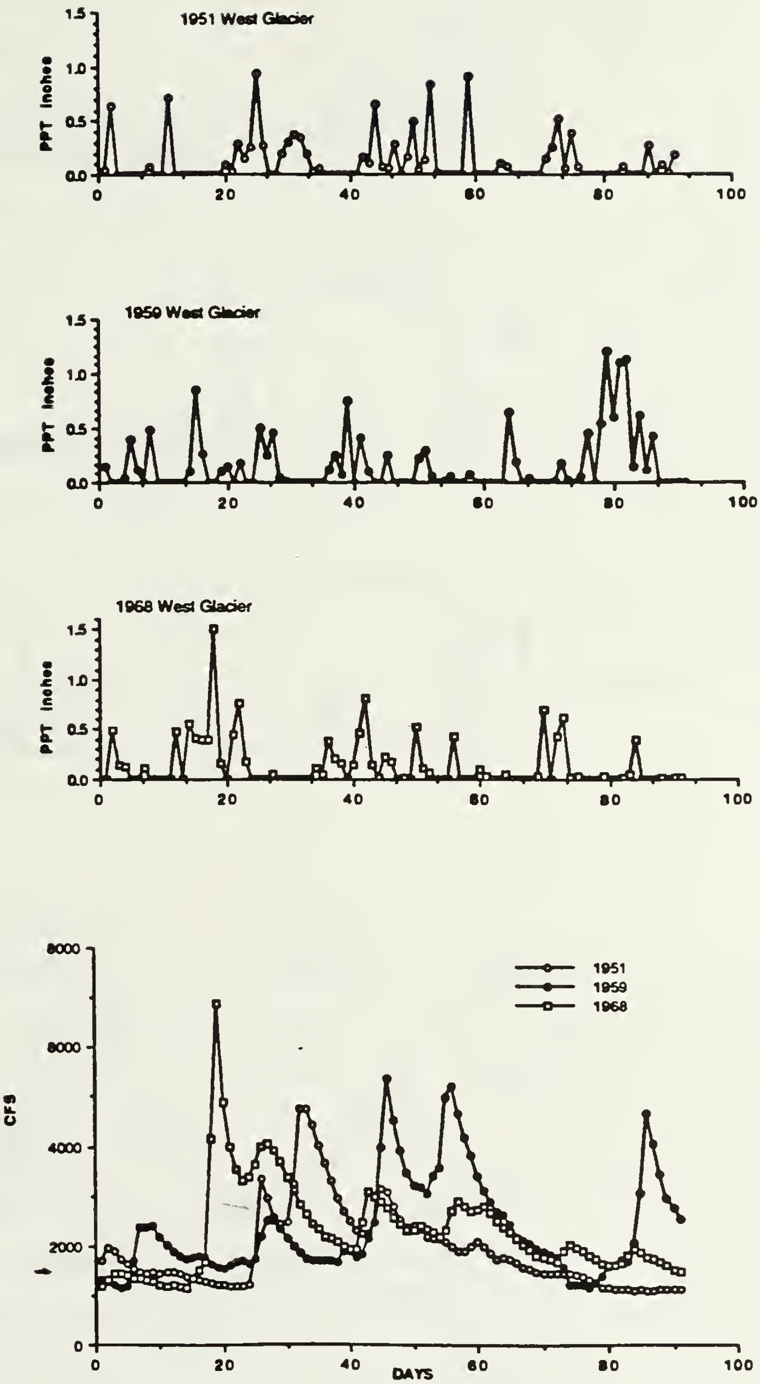


Figure 15. Precipitation and corresponding discharge in the Middle Fork of the Flathead River on years with an autumnal flooding event (ie. >3x the long term mean autumnal flow) from 1951 through 1970. Time expressed as days from September 1 through November 30.

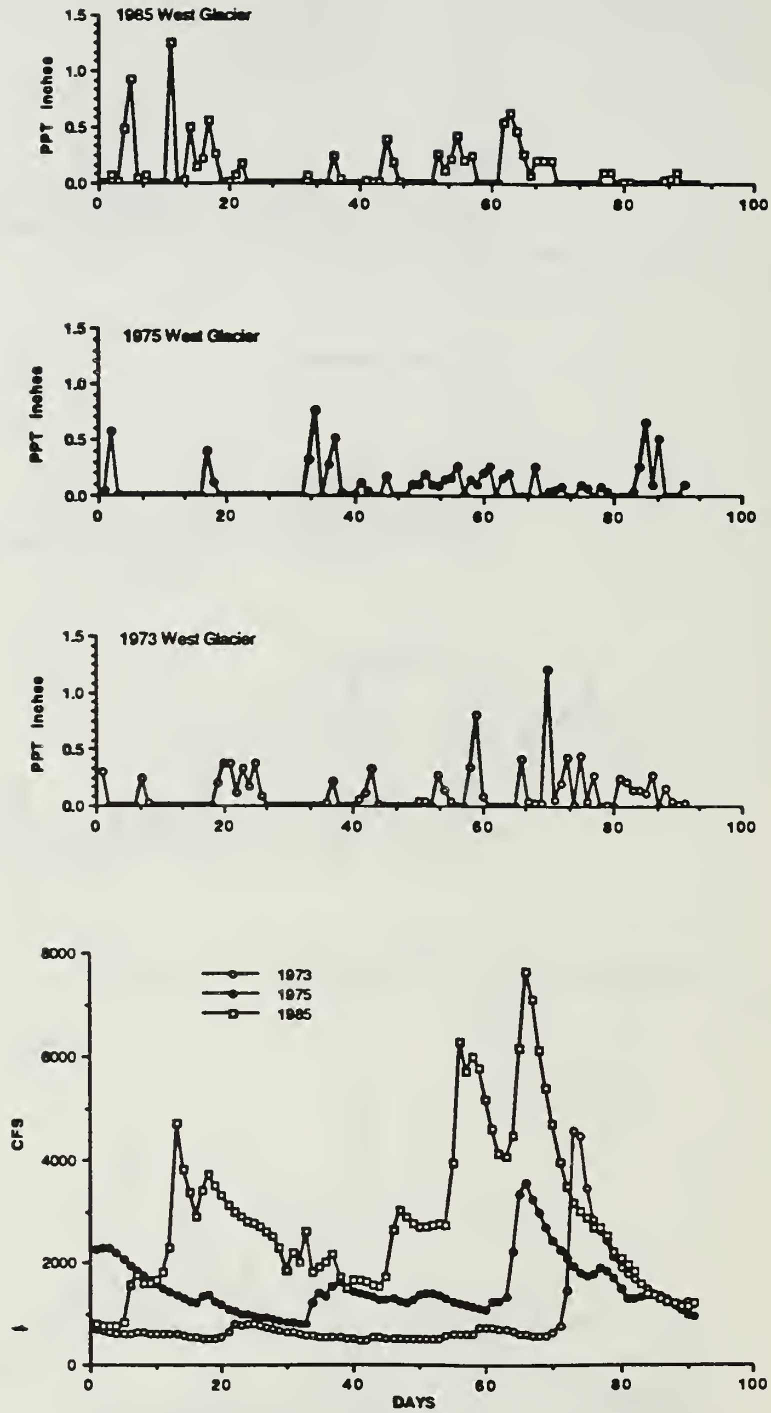


Figure 16. Precipitation and corresponding discharge in the Middle Fork of the Flathead River on years with an autumnal flooding event (ie. >3x the long term mean autumnal flow) from 1971 through 1986. Time expressed as days from September 1 through November 30.

corresponding flooding event in either the North or Middle Forks. In contrast in 1947, there was relatively little rainfall recorded in Kalispell while there was a significant increase in discharge in both the North and Middle Forks around Day 50 (October 20).

After 1950 and the advent of precipitation records at West Glacier, the relationship between autumn rainfall data and discharge data remains poorly correlated. For example, in 1975 a small flooding event occurred in both the North and Middle Forks, but there is no discernable increase in rainfall at West Glacier preceding the flooding. Generally, flooding events in the autumn, particularly those occurring early in the fall, must be driven by rainfall since there is typically no significant accumulated snow pack. Therefore, one must conclude that the precipitation occurring at either Kalispell or West Glacier is not an adequate indicator or measure of precipitation occurring elsewhere in the higher portions of these two watersheds. Heavy rainfall may occur along the continental divide in both the North and Middle Fork drainages with little corresponding rainfall low in the valley.

SPRING RUNOFF PATTERNS

Spring streamflows were analyzed to determine what factors regulate volume, pattern, and timing of mean daily discharge (Q). Spring streamflows for the North Fork and Middle Fork can be seen, ranked by maximum discharge, for each year from 1940 through 1986 in Appendices A_1 and A_2. Examination of total daily Q from the North and Middle Forks for the period of April 1 through June 30 compared with recorded snow pack not surprisingly revealed a close correlation between the quantity of water available for runoff and the actual measured total discharge ($p < 0.001$, Spearman Rank). Discharge for the North and Middle Forks, the Swan River, and Swift Creek were compared with temperature and precipitation data from West Glacier, Bigfork, and Whitefish, respectively (see Appendix B). Nonparametric statistics were also applied to these comparisons to determined which factors appear to initiate and drive spring runoff.

It was determined that the spring runoff was primarily driven by warming temperatures as daily maximum air temperature degree days above 50 °F ($p < 0.01$). A positive slope in the temperature regime and the accumulation of degree days resulted in increasing discharge. When temperatures cooled discharge would decrease. However, the peak in discharge was determined by the available accumulated water as snow pack. Thus, the falling limb of the hydrograph was forced by the depletion of source waters. The temperature to discharge relationship is most easily seen in illustrations of summation of degree days (>50 °F) and runoff discharges (Figs. 17 - 21). From these graphs one can observe that with a greater slope in the temperature summation line there was a corresponding increase in discharge and as the slope of the line tended to flatten (approach 0) the discharge would decrease. From these data it was concluded that, indeed, the onset and rising limb of the spring runoff is primarily driven by increasing temperatures.

ANALYSIS OF TRANSFORMED DISCHARGE DATA

Since it was determined that temperature is the primary factor affecting the pattern of spring runoff and that the volume of runoff is governed principally by snow pack, these variables needed to be factored out of an analysis of whether there has been a change in runoff pattern that might be attributable to timber harvest. Comparison between years also required comparison to changes that may be also observed in a control watershed. For this analysis, the Middle Fork was used as the control stream, since that drainage has experienced relatively little timber harvest in comparison to either the North Fork or the Swan River drainages.

Because it was determined that spring runoff for most years is driven primarily by warming temperatures, an analysis was done on the April 1 to June 30 (ie. runoff period) temperature regimes of each year from 1940 through 1987. An ordination analysis was then completed to compare similar temperature regimes of the 1940's (ie. before extensive timber harvest) to years of the 1970's and 1980's (after and during extensive timber harvest). These analyses

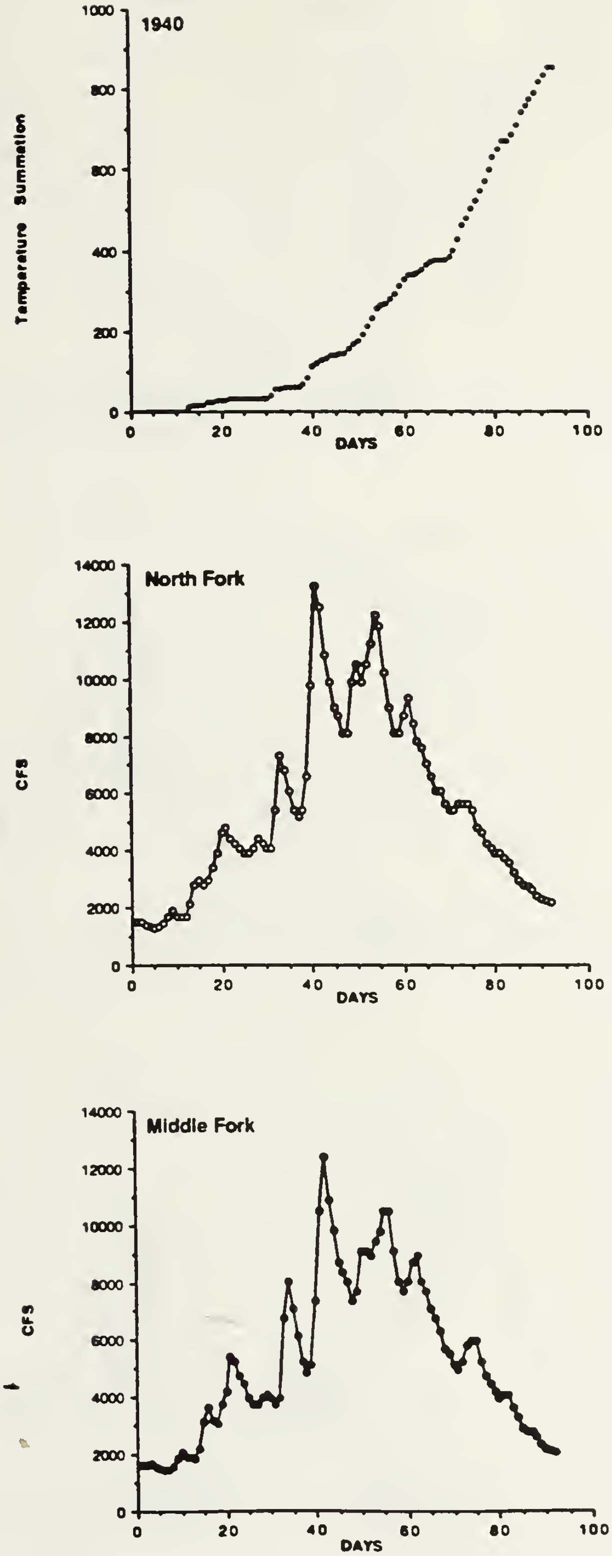


Figure 17. Daily maximum air temperature summation of degree days >50 °F at West Glacier and discharge pattern in the North and Middle Forks for the period of April 1 through June 30, 1940.

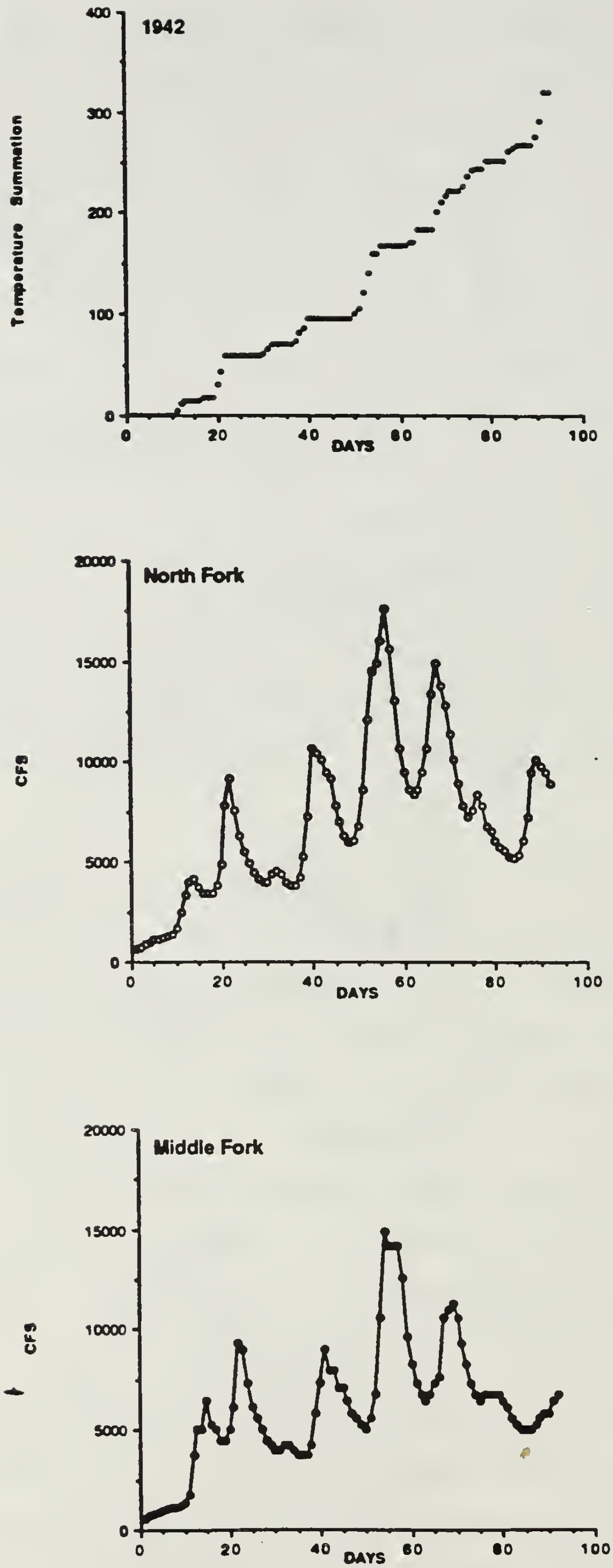


Figure 18. Daily maximum air temperature summation of degree days >50 °F at West Glacier and discharge pattern in the North and Middle Forks for the period of April 1 through June 30, 1942.

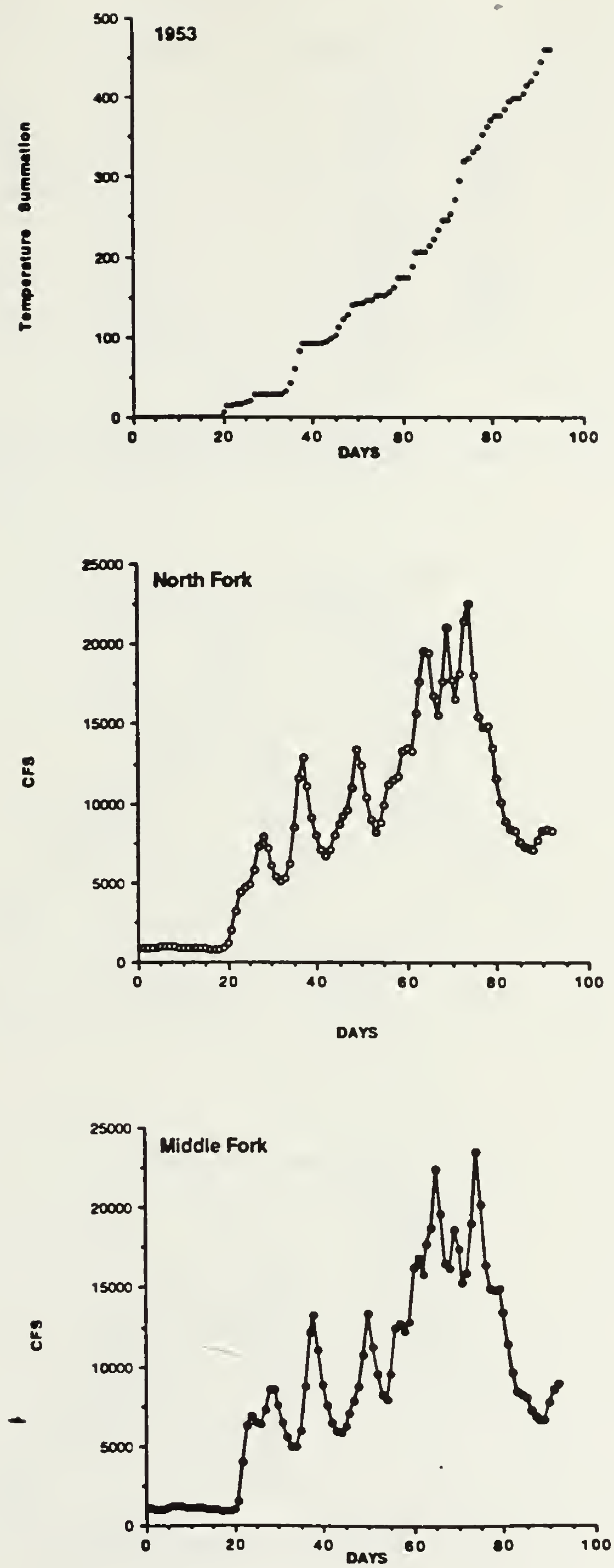


Figure 19. Daily maximum air temperature summation of degree days >50 °F at West Glacier and discharge pattern in the North and Middle Forks for the period of April 1 through June 30, 1953.

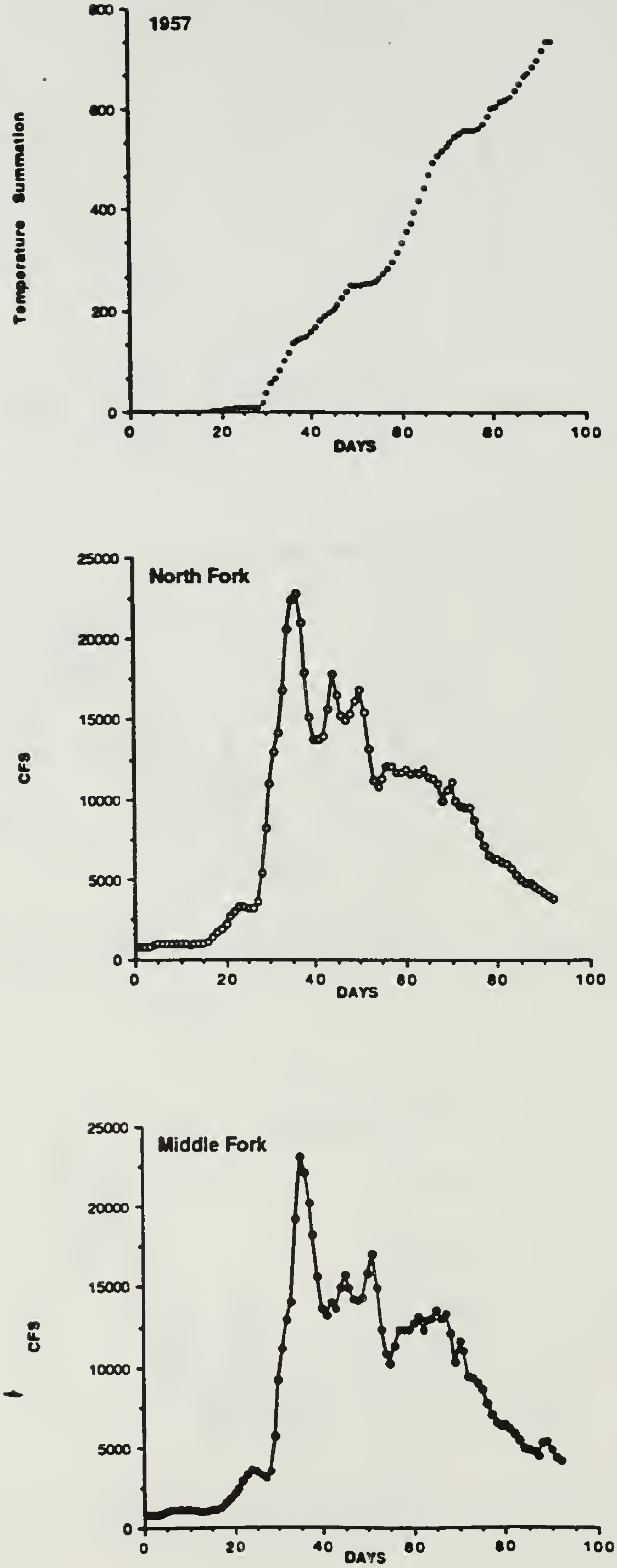


Figure 20. Daily maximum air temperature summation of degree days >50 °F at West Glacier and discharge pattern in the North and Middle Forks for the period of April 1 through June 30, 1957.

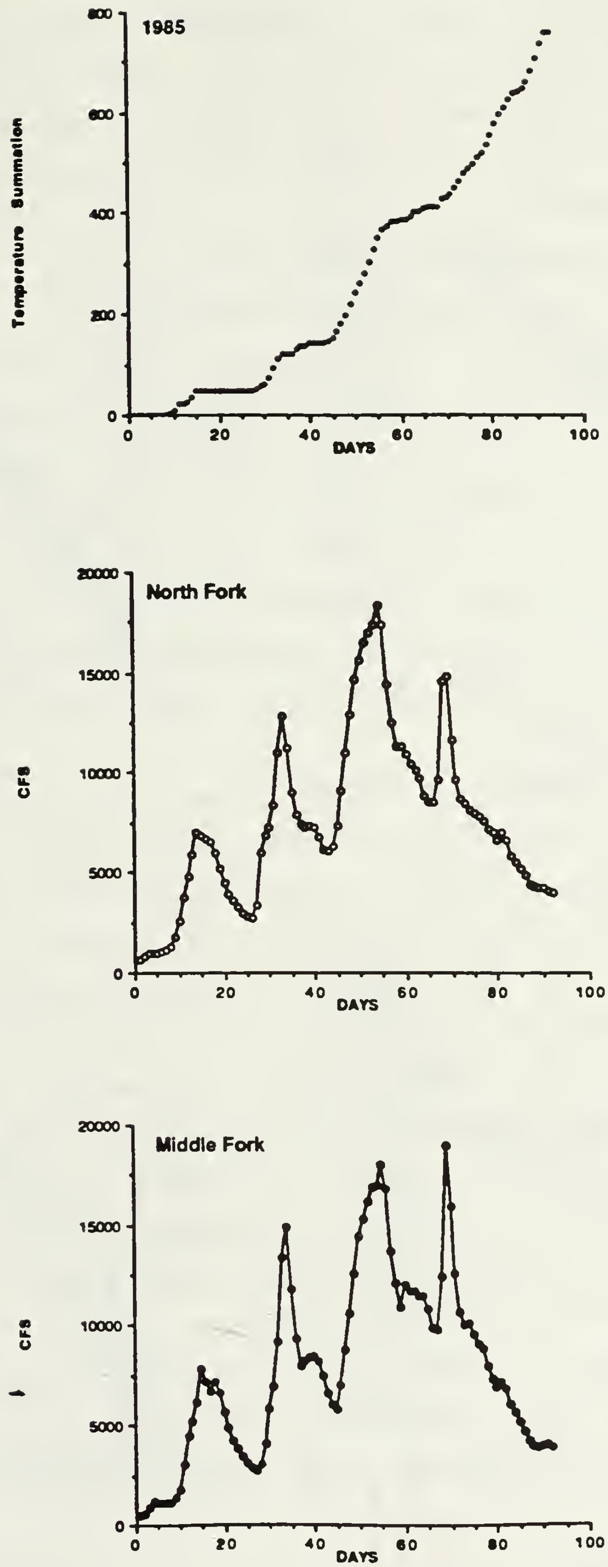


Figure 21. Daily maximum temperature air summation of degree days >50 °F at West Glacier and discharge pattern in the North and Middle Forks for the period of April 1 through June 30, 1985.

indicated three groupings of temperature pattern similarity; a 1940 - 1977 - 1986 grouping, a 1944 - 1976 - 1983 grouping, and a 1945 - 1975 - 1984 grouping. Other years did not have similar enough temperature regimes to make valid comparisons of response in stream discharge.

The discharge data from each of these years expressing a similar temperature profile were transformed by dividing the mean daily discharge by the water equivalent snow pack on April 1 of that same year. Thus, the inherent variability in streamflow response that may be derived from snow pack alone was minimized. Streamflow, as mean daily discharge, was then accumulated through time to establish the slope of the runoff event. The steeper the slope of the accumulated discharge the earlier that year's discharge arrived in the stream. The slopes of the accumulated discharges were compared between years for each temperature group, and within each of the three river systems.

These comparisons revealed that the slopes of the discharge patterns of the North Fork and Swan River tended to be higher in the 1970's and 1980's, relative to those in the 1940's than did those of the Middle Fork (Figs. 22, 23, and 24). Among all comparisons, in only one case was the slope of a recent discharge pattern in either the North Fork or Swan River not greater in relation to its comparative 1940's discharge slope than would be predicted based on slope relationships expressed in the Middle Fork.

Based on these results of discharge pattern among years of similar temperature profiles, comparing the Middle Fork as a drainage basin with relatively little timber harvest with that of the North Fork and Swan River drainages, which have had far more extensive harvest; it appears that the two drainages with extensive timber harvest have experienced discharge coming earlier in the runoff season in comparison to the control drainage.

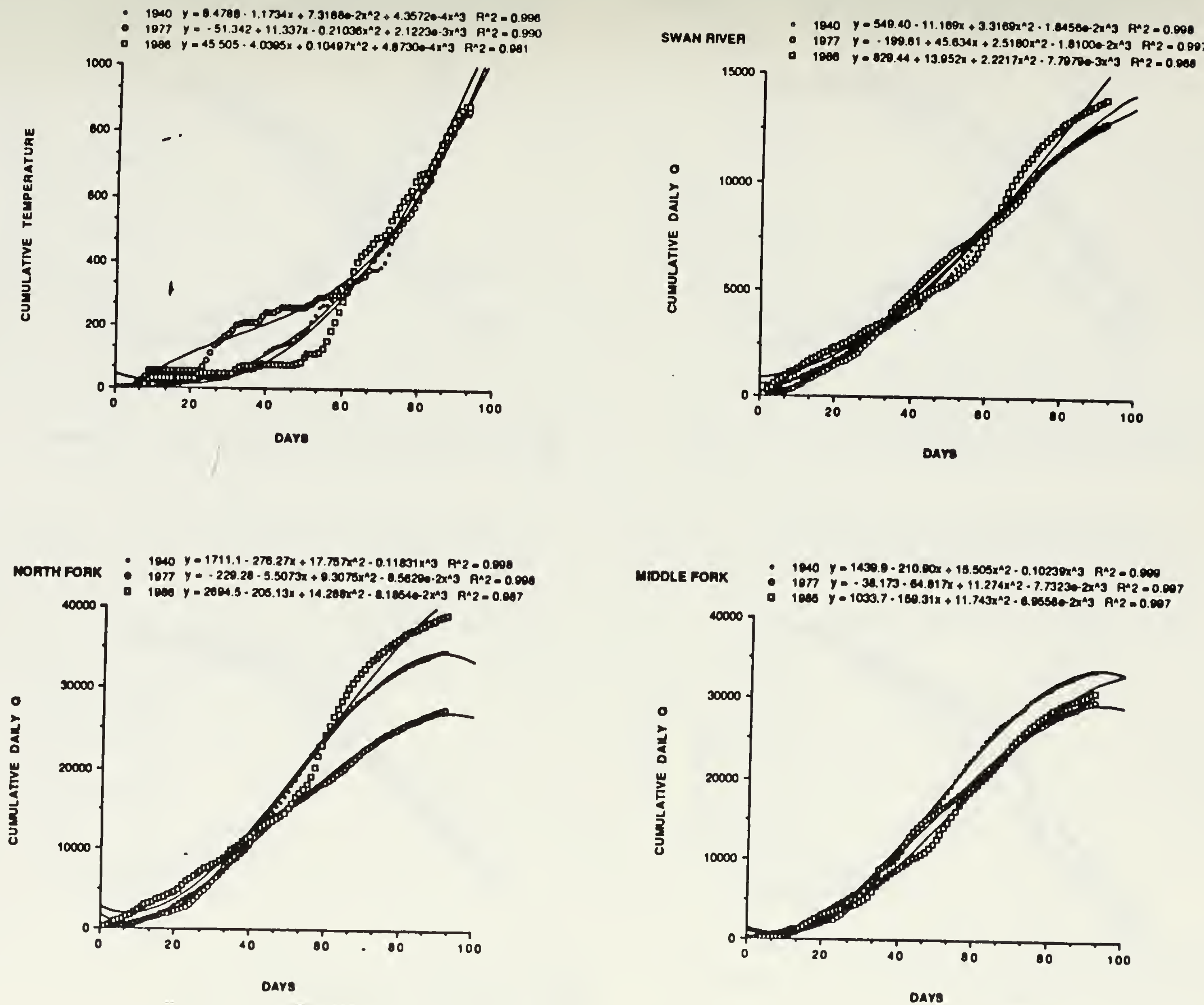


Figure 22. Accumulated mean daily discharge for the North Fork, Swan River and Middle Fork among years with similar spring temperature regimes comparing years 1940, 1977, 1986.

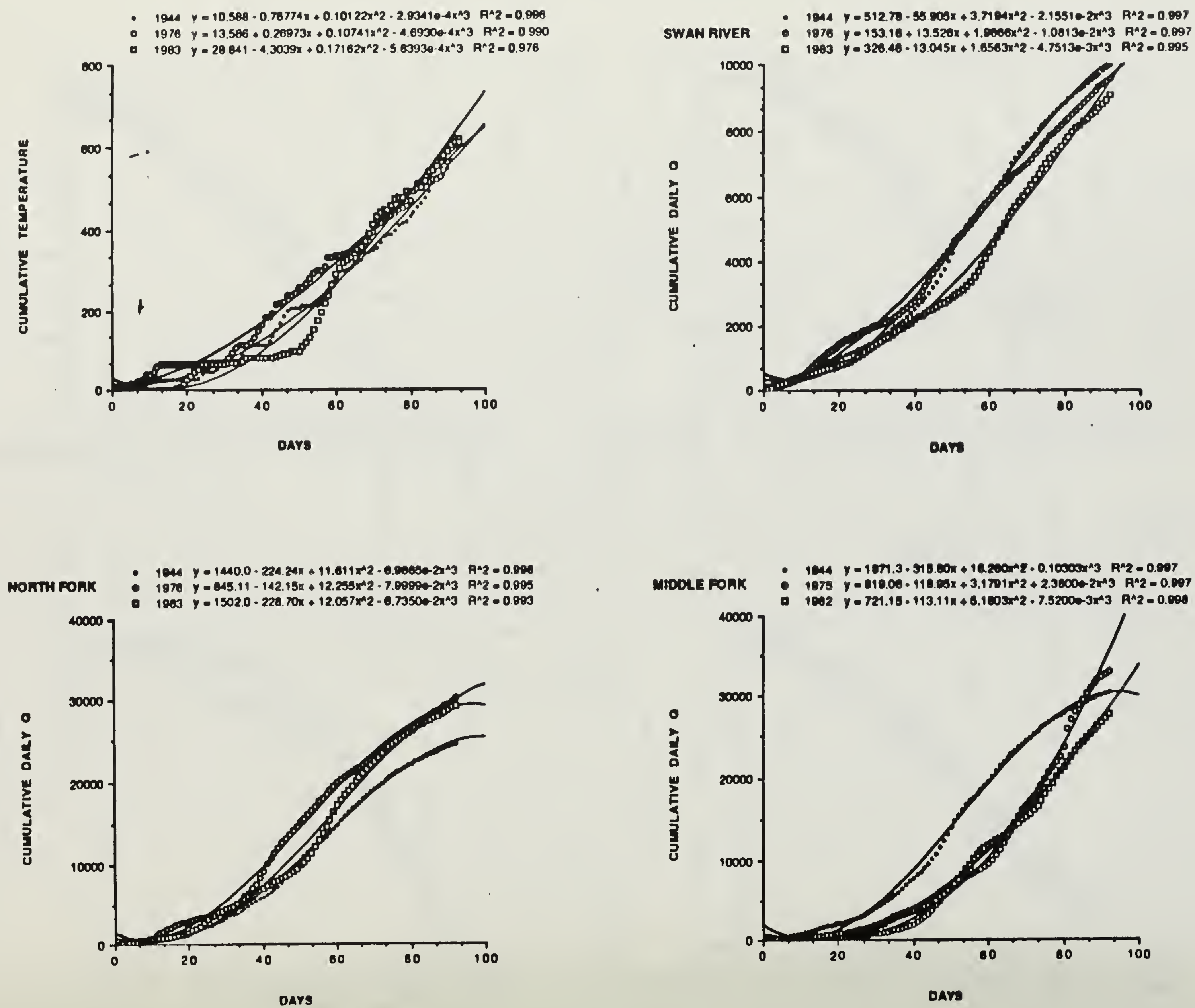


Figure 23. Accumulated mean daily discharge for the North Fork, Swan River and Middle Fork among years with similar spring

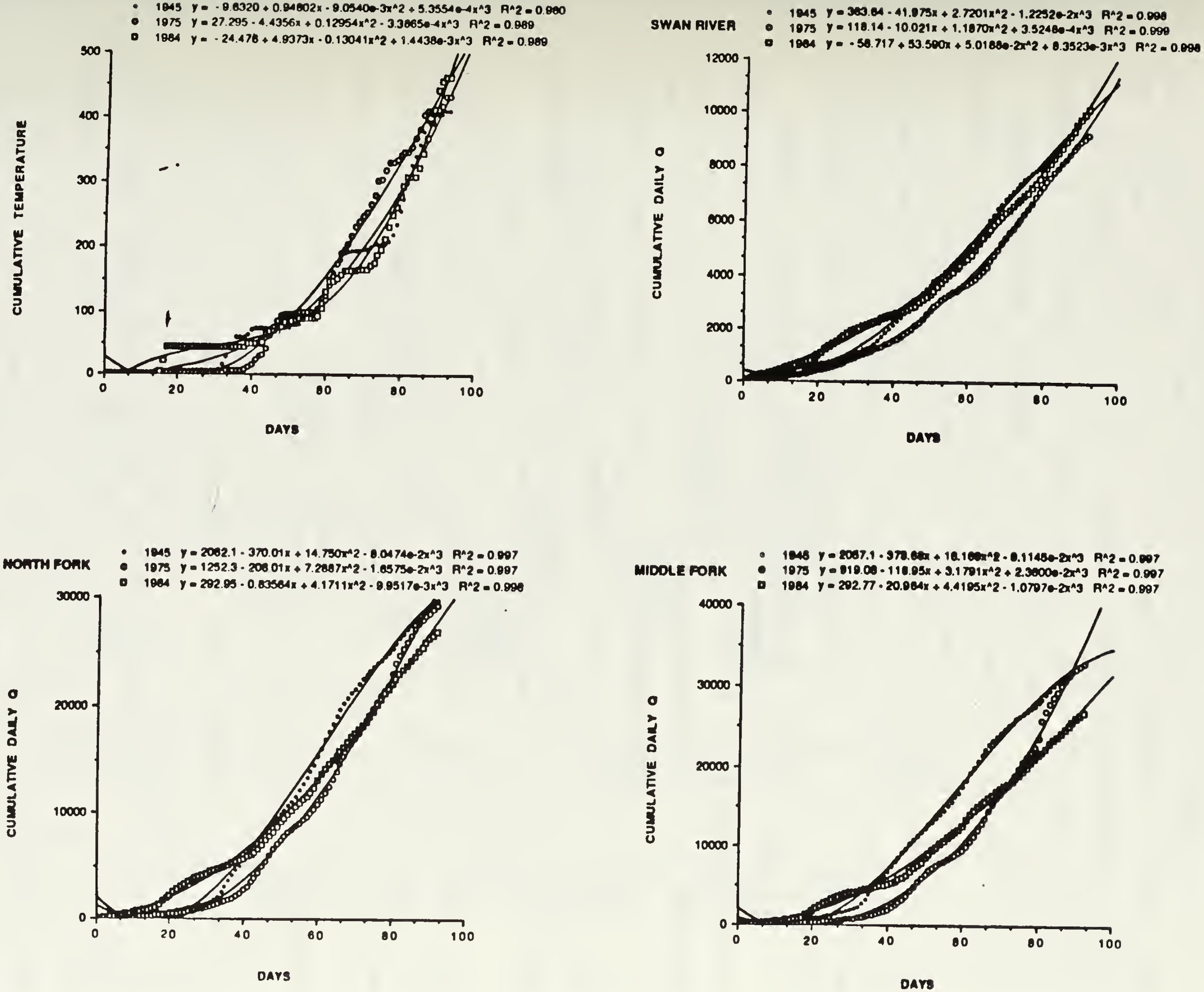


Figure 24. Accumulated mean daily discharge for the North Fork, Swan River and Middle Fork among years with similar spring temperature regimes comparing years 1945, 1975, 1984.

RELATIONSHIP OF ANNUAL MAXIMUM AND MINIMUM Q

Comparison of streamflow volumes and regimes from small, experimental watersheds have shown that after timber harvest the stream responds more quickly to rainfall events and reaches a higher maximum discharge than occurred prior to harvest for a similar precipitation event (Cheng 1989). Also, baseflow of most streams is derived from groundwater stream interactions (Davis and DeWiest 1966). In the case of a watershed which as been harvested the water table is often higher than prior to harvest since evapotranspiration from the forest canopy has been reduced. However, in some cases the water table may be lowered as landscape stability and retention of rainfall may be altered by harvest, reducing groundwater recharge.

A factor that may have important consequences to stream biota in the Flathead Basin is the change in relationship between maximum discharge and minimum discharge for any given year. In other words, with a given water supply to a stream derived from snowmelt and rainfall, if the stream is increasing in maximum discharge and decreasing in minimum discharge there may be significant implications for both resident biota as well as adfluvial species.

Comparison of Qmax/Qmin were made for each drainage, unfortunately all the low order stream systems have relatively short data records and thus no long term trends could be made. Also the long term database on the Swan River at Bigfork is below Swan Lake which greatly modifies discharge patterns. However, direct comparison of Qmax/Qmin was possible for the long term databases of the North and Middle Forks (Figs. 25 and 26). These graphs illustrate that although there is considerable interannual variability, there is a general trend in the Middle Fork toward a reduction in the Qmax to Qmin relationship and that in the North Fork there is a general trend toward an increase in Qmax:Qmin. These relationships suggest that the Middle Fork is becoming less "flashy" (ie. for a given water budget Qmax tends to be lower and Qmin greater), while in contrast the North Fork appears to be more "flashy" during the past 20 years since extensive harvest than prior to timber harvest.

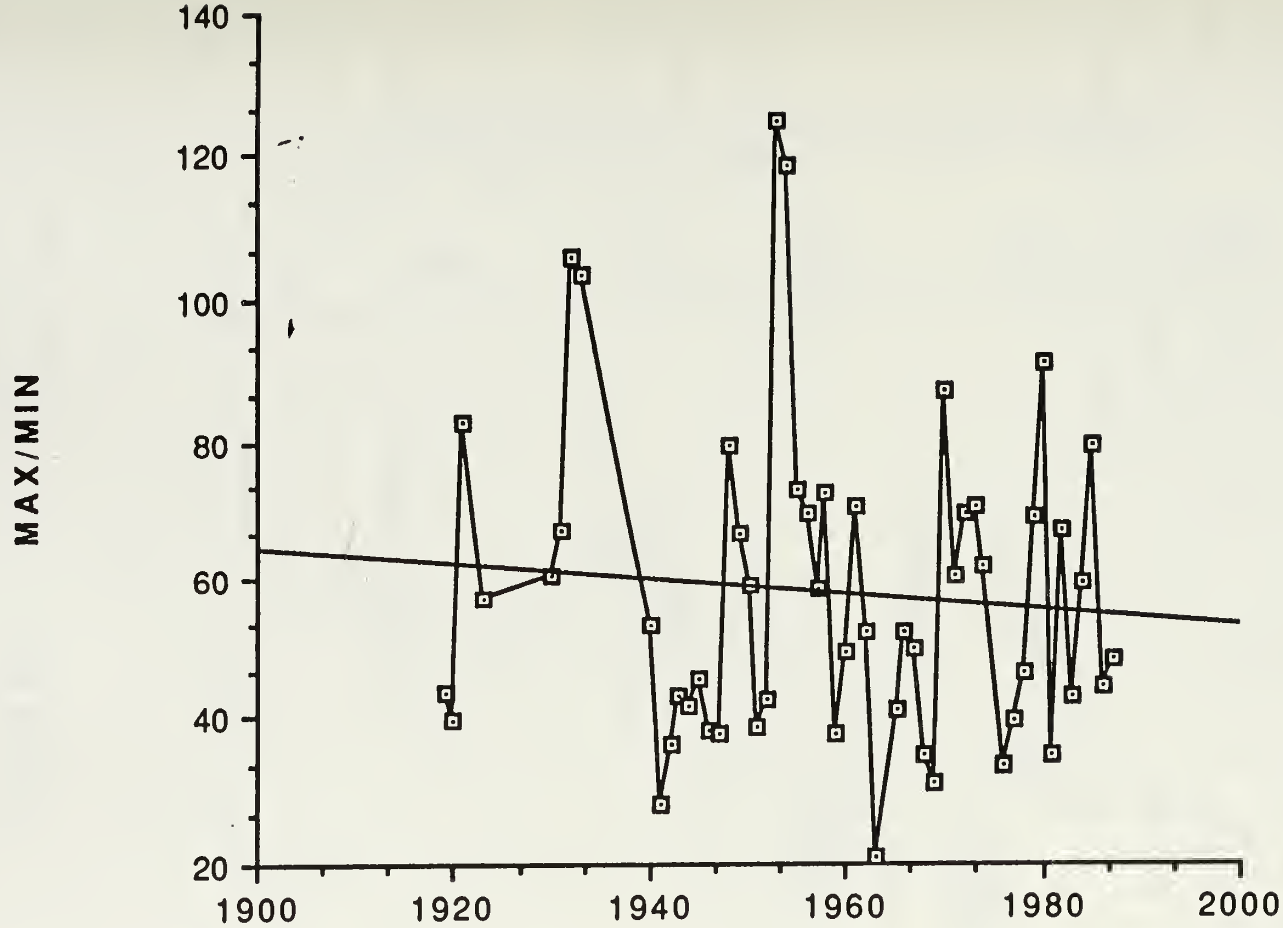


Figure 25. Annual maximum discharge to minimum discharge relationship for the Middle Fork of the Flathead River for the period of record.

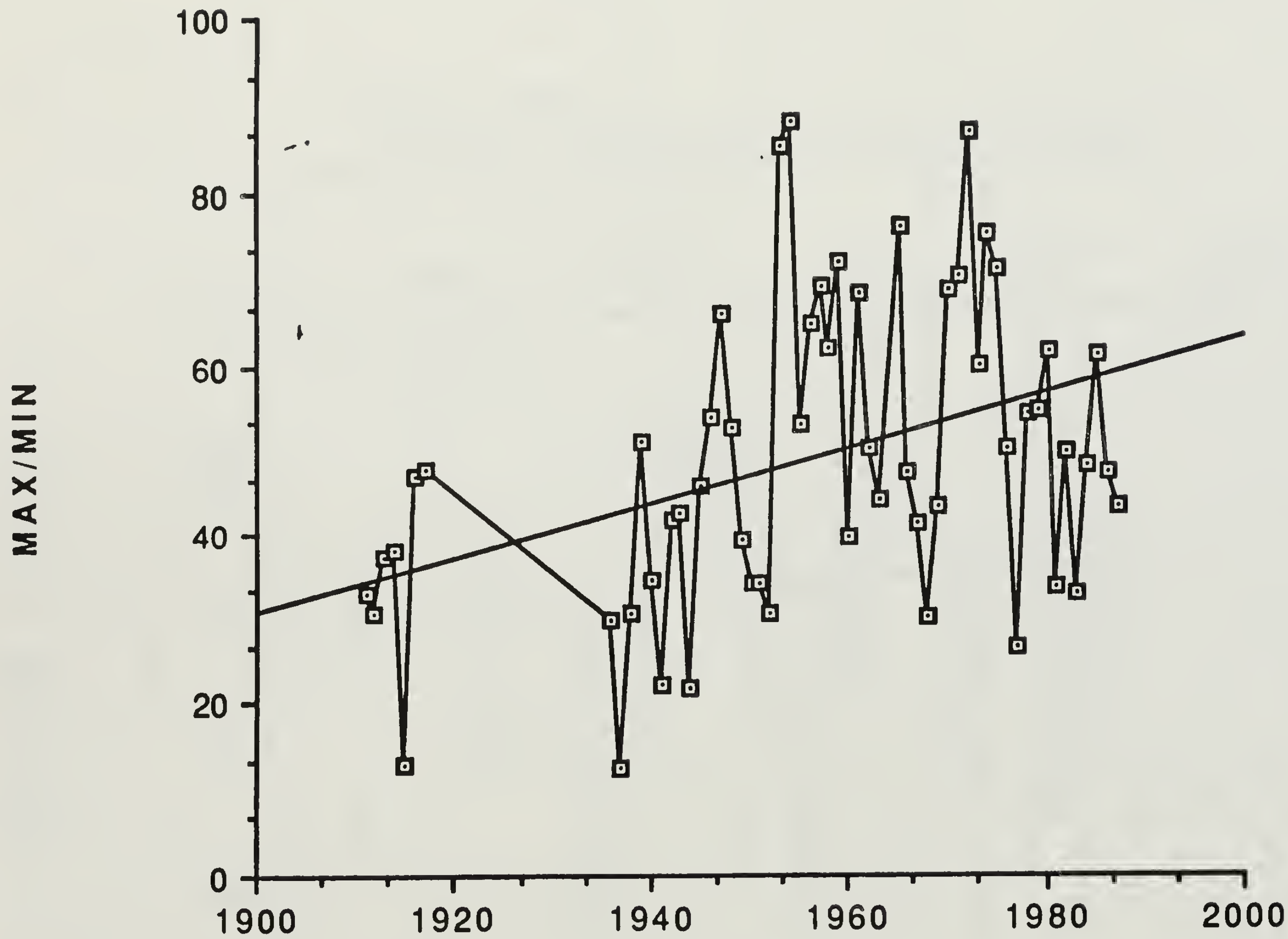


Figure 26. Annual maximum discharge to minimum discharge relationship for the North Fork of the Flathead River for the period of record.

LONG TERM TRENDS IN RELATIONSHIP OF DISCHARGE:PPT RATIOS

An analysis of total annual discharge to total annual precipitation revealed a consistent relationship of decreasing Q:PPT in both the North and Middle Forks (Fig. 27). This relationship has tended to begin to flatten since 1960, however the downward trend is continuing. This is likely due to a general response within these drainages of long term recovery from extensive fire disturbance earlier in this century. Thus, as land areas recover from being burned and become increasingly vegetated, including encroachment of forest into meadows, increased evapotranspiration should decrease overall streamflow.

SUMMARY

The examination of the historical records of streamflow, temperature, precipitation, annual snow pack, timber harvest and natural deforestation indicate a series of very basic conclusions regarding the effects of timber harvest on streamflow quantity and regime. A broad spectrum of analysis were conducted on these data of which only the highlights have been presented herein.

During the end of the last century and the early decades of this century there were frequent and large forest fires which affected very large areas of forest land. Between 1880 and 1930 over 1.5 million acres of Flathead Basin timbered lands were involved in forest fire. This represents roughly one third of all of the Flathead Basin above Flathead Lake and does not include fires that occurred in the North Fork, north of the U.S. - Canadian border. Although the amount of area that has been harvested during the past thirty years is much less than this, it is significant. Since 1950, over 93,000 acres have been harvested from the Swan River, North Fork, Lazy Creek and Swift Creek drainages alone (ie. not including the Swan Front, the South Fork around Hungry Horse Reservoir, Tally Lake area, Lake Mary Ronan area, etc.). Furthermore, it remains unknown if fire has a

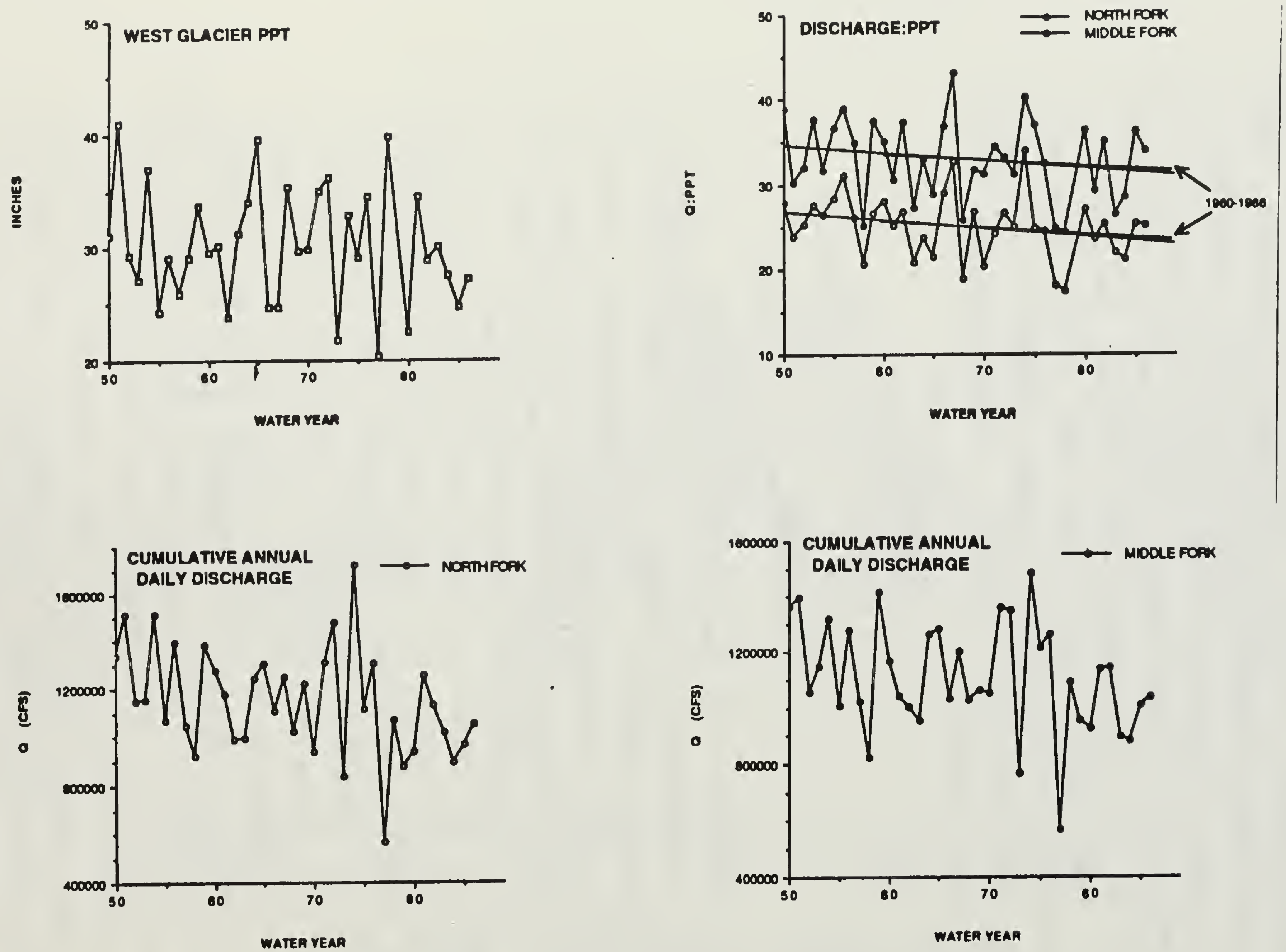


Figure 27. Comparison of annual precipitation (PPT) at West Glacier and annual discharge (Q) in the North and Middle Forks of the Flathead River.

similar or dissimilar effect on streamflow as an equivalent area of timber harvest. Nonetheless, there has been a trend of decreasing forest fire since the 1930's and an increase in timber harvest since the 1950's, with a distinct period of watershed recovery in between.

An analysis of autumnal precipitation and flooding events revealed that the data available is inadequate to resolve the issue of whether there has or has not been a change in the response of large river system streamflow since the onset of increased harvest pressure. There was no distinct relationship between specific rainfall events recorded at either Kalispell or West Glacier and a flooding event in the North and Middle Forks. Since there is very little stored water in these drainages during the autumn in the form of snow pack, it is reasonable to conclude that floods at that time of year must be driven by significant rainfall events. However, based on these data, as well as practical experience, rainfall along the continental divide is not always reflected in a proportional way in the valleys. Thus, inorder to derive a better understanding of autumnal flooding events more detailed data collection is necessary.

Streamflow was also analyzed for changes in regime. It was determined that the rising limb of the hydrograph among Flathead Basin streams is primarily driven by warming temperatures and that runoff volume is a function of annual snow pack. This, however, does not include extremely high flooding events, like the flood of 1964, which are driven by very high rainfall on a deteriorating snow pack and typically occur after June 1. An analysis of discharge pattern was conducted on streamflow data which were transformed by dividing the mean daily Q by the water equivalent snow pack for that year. Years with similar temperature regimes, contrasted to compare 1940's discharge years with 1970 and 80's discharges, were determined by an ordination procedure. Years with similar temperature regimes were compared to assess whether streamflows were occurring earlier, later or with no change through time in those drainages that have received a high level of timber harvest. These analyses indicated that during the 70's and 80's (ie. with higher levels of timber harvest) the North Fork and Swan River discharges

were occurring at an earlier time than in the Middle Fork, the control stream.

Analysis of long term changes in annual streamflow with respect to the relationship of maximum discharge to minimum discharge in the North and Middle Forks indicated a trend toward a decreased Qmax:Qmin in the Middle Fork and an increase in Qmax:Qmin in the North Fork. This suggests that the increased timber harvest in the North Fork may be resulting in that stream becoming increasingly flashy, while in contrast, the Middle Fork is becoming less flashy, perhaps due to the overall reduction of fire in the drainage basin.

In conclusion, it appears that indeed there is an effect of timber harvest on the discharge pattern of streams and rivers in the Flathead Basin and that some of these changes are measurable even within the very large drainage basins of the North Fork and Swan River. The effects tend to manifest as an earlier spring runoff and as an increase in the relationship of annual maximum to annual minimum discharges. Temporal condensing of high autumnal rainfalls even within very long databases could not be determined because of inadequate accuracy in the relationship between the locations of valley recorders and actual precipitation.

ACKNOWLEDGEMENTS

I thank Drs. C. N. Spencer and J. A. Stanford for their constructive comments throughout the analysis of the historical data base. I thank C. Key, B. Schultz, D. Sirucek for assisting me with obtaining data from their respective agencies. M. Enk, J. Fraley, C. Hess, W. Page, B. Schultz, D. Sirucek, and P. Snow made helpful suggestions to improve the report. A special thanks to Jim Stimson of the Montana Natural Resource Information System for his assistance in obtaining USGS and NOAA data.

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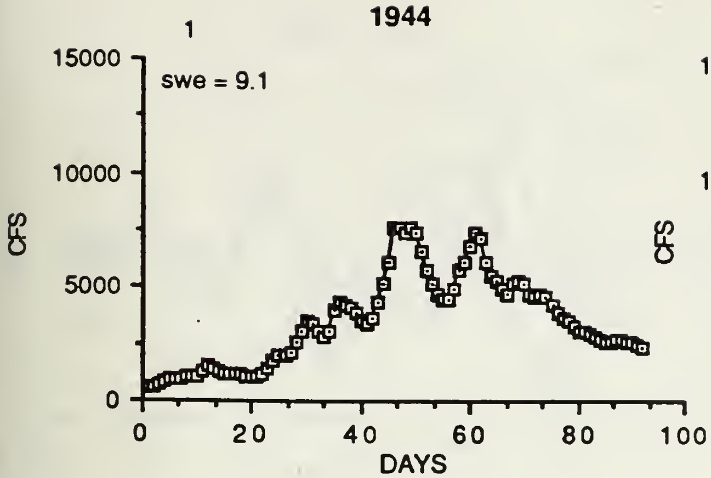
Appendix A1. Discharge patterns of the spring runoff (April 1 through June 30) in the North Fork of the Flathead River ranked by year of maximum discharge from 1940 - 1986.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10000
5000
0
CFS
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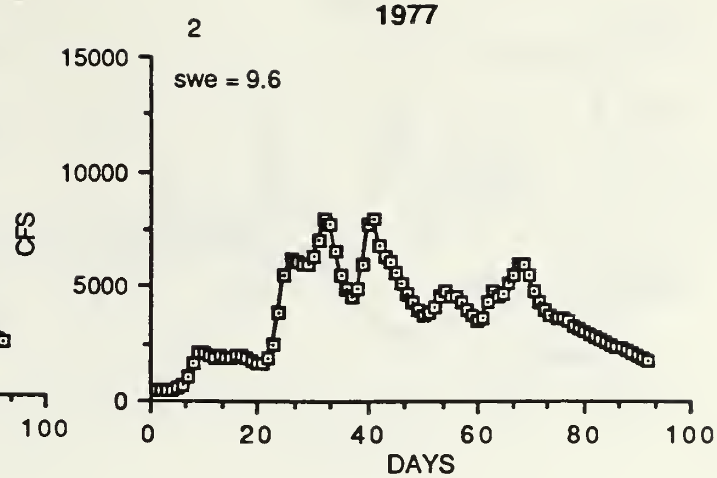
20
40
60
80
100
DAYS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60
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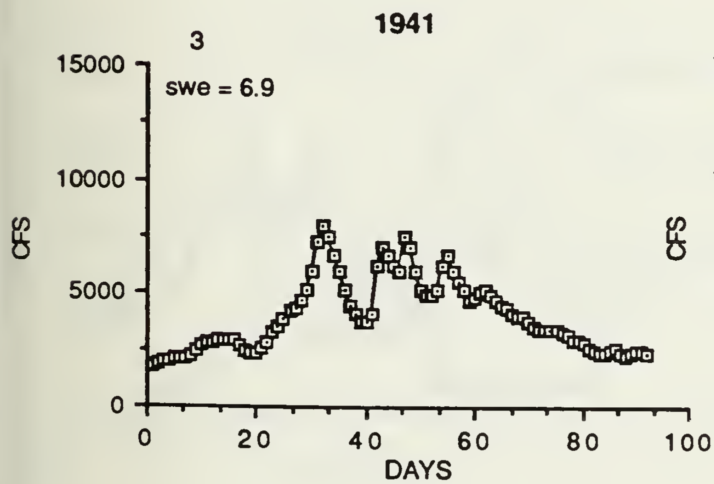
DAYS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5000
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CFS
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40
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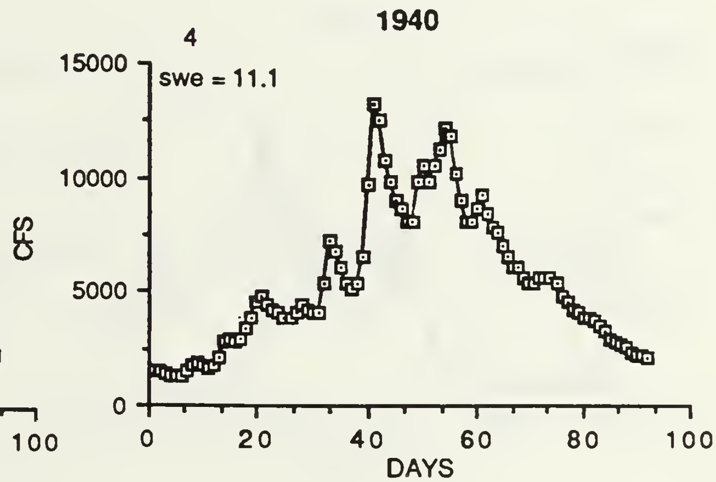
DAYS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CFS
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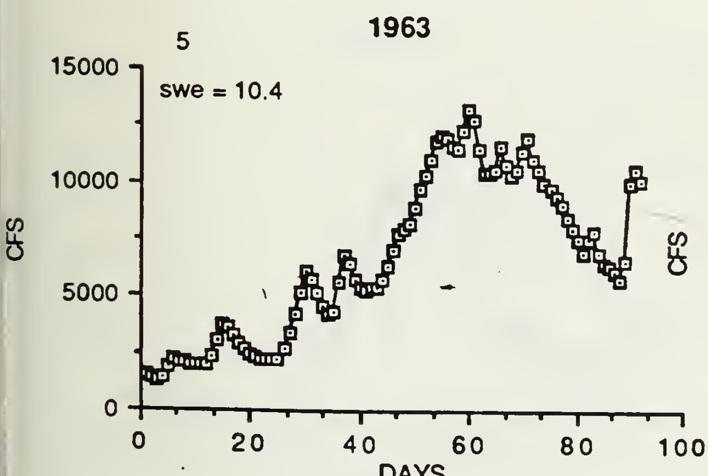
DAYS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CFS
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40
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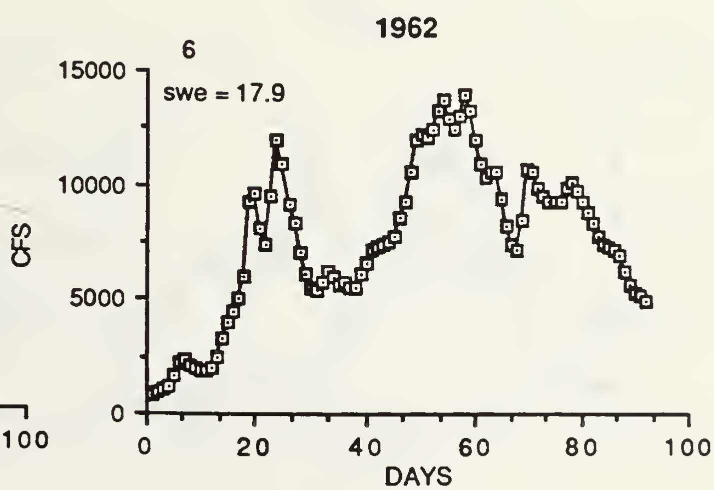
80
100
DAYS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CFS
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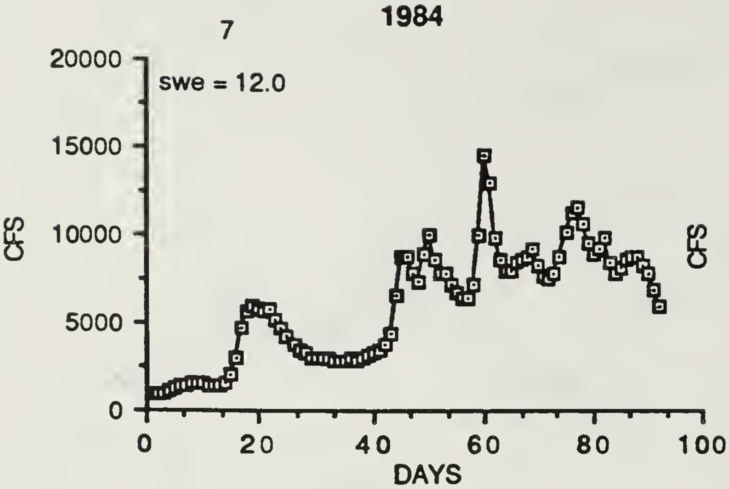
100
DAYS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DAYS
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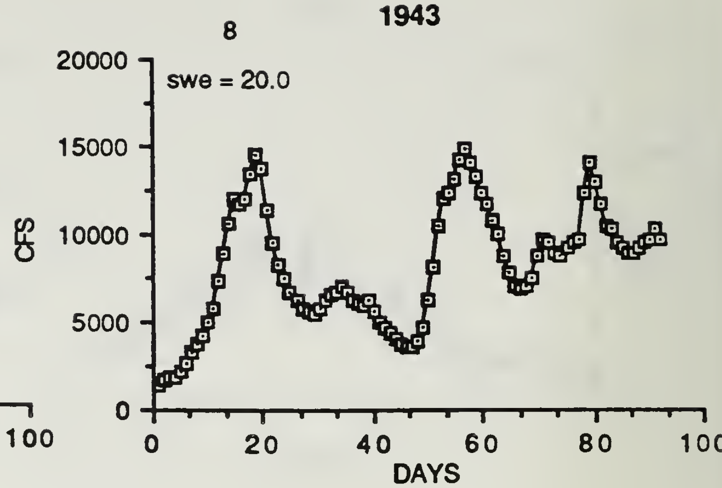
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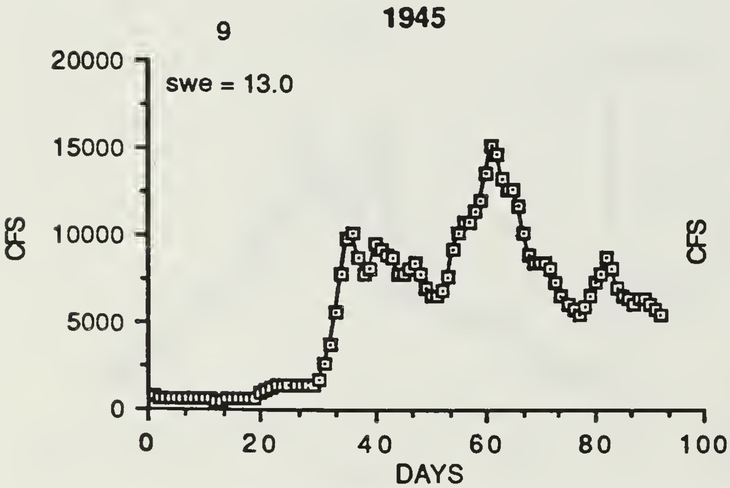
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DAYS
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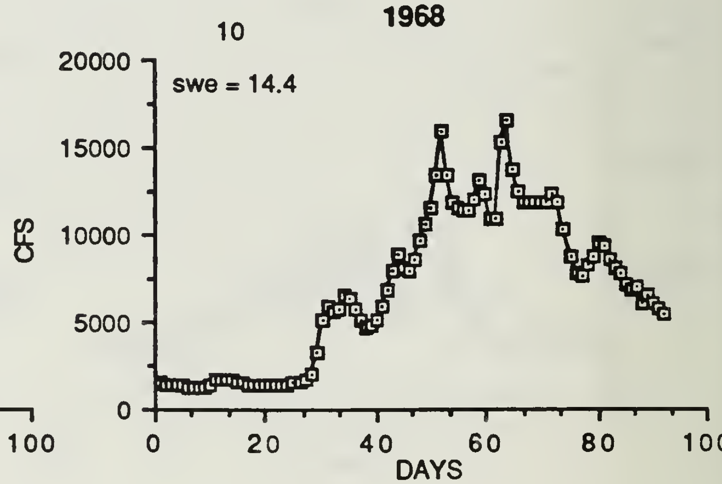
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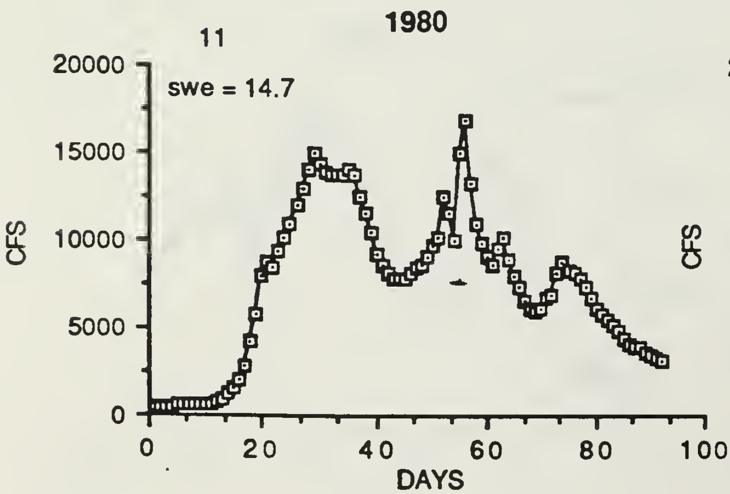
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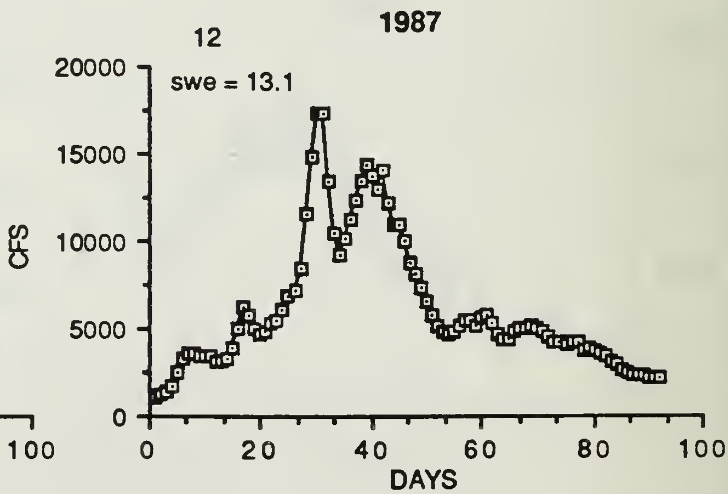
80
100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CFS
DAYS
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10000
15000
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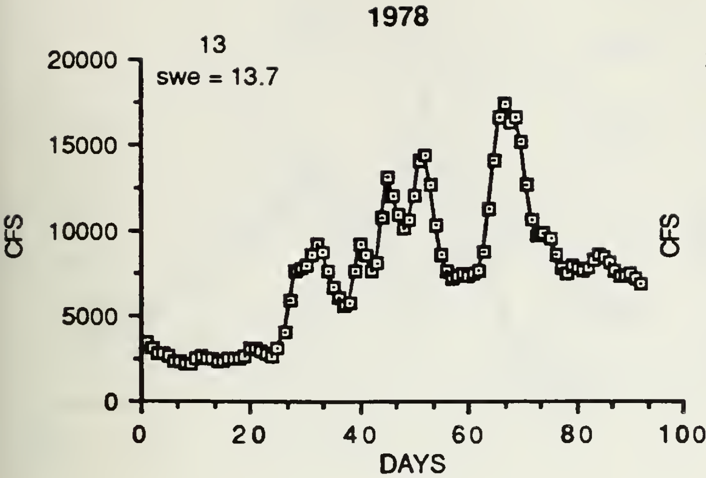
60
80
100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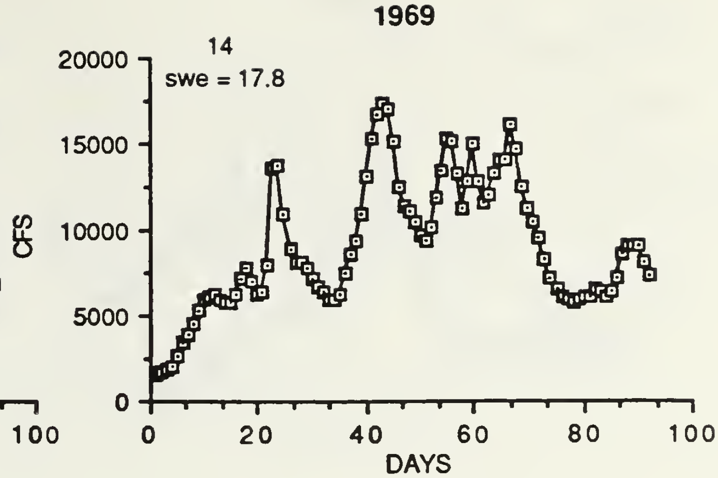
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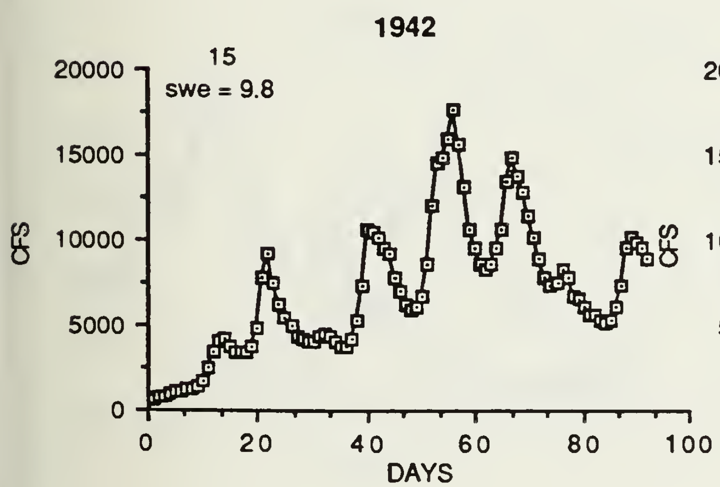
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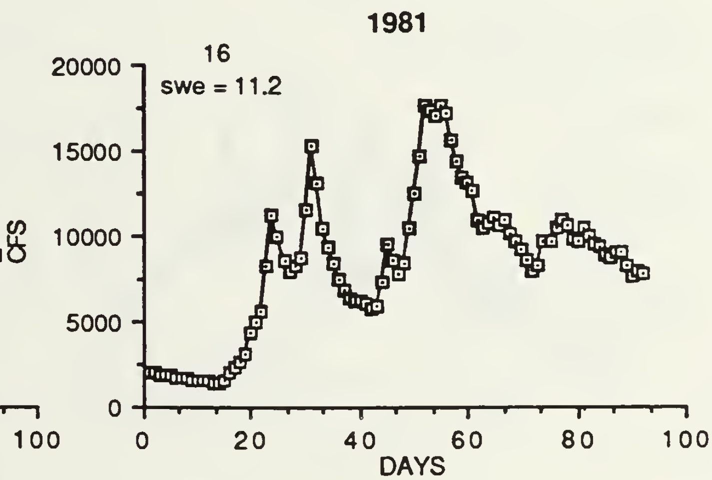
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80
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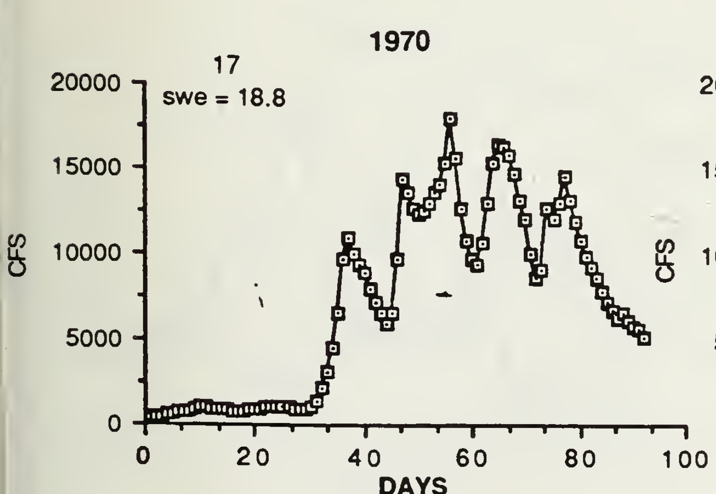
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DAYS
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80
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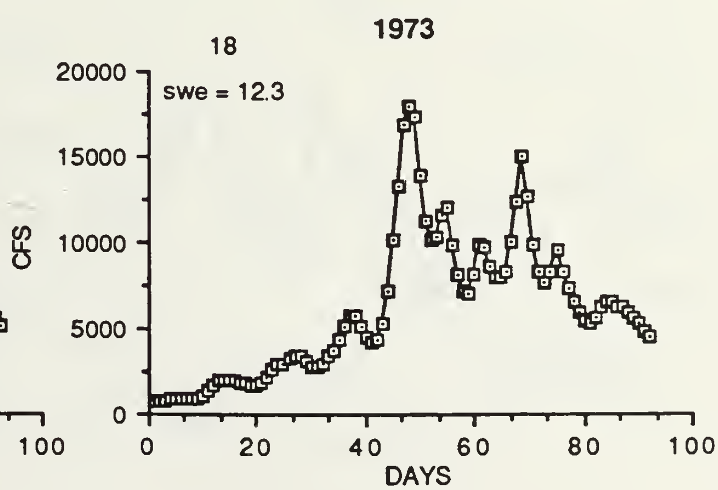
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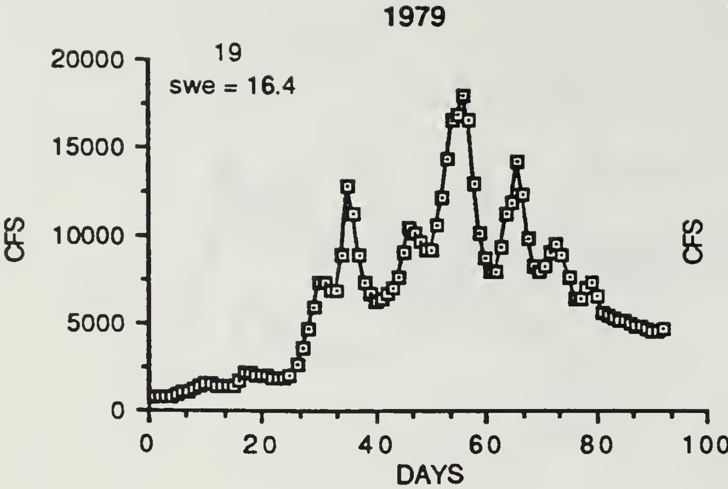
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CFS
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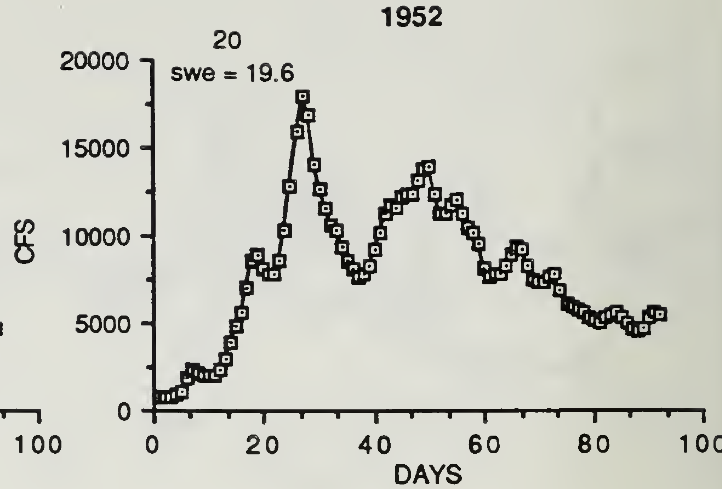
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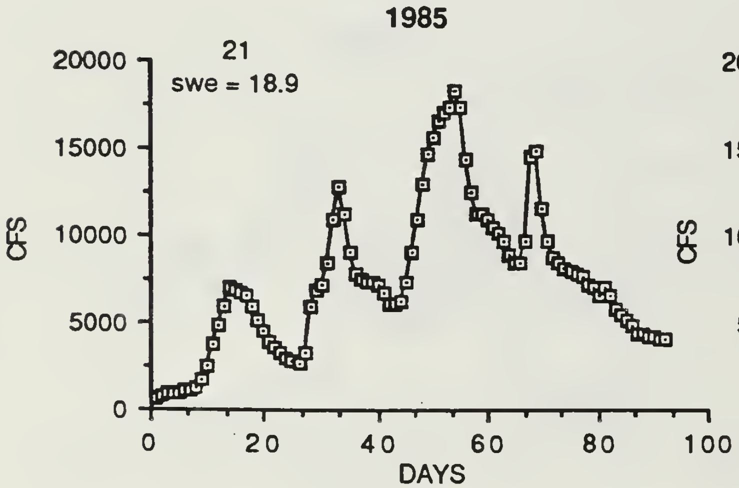
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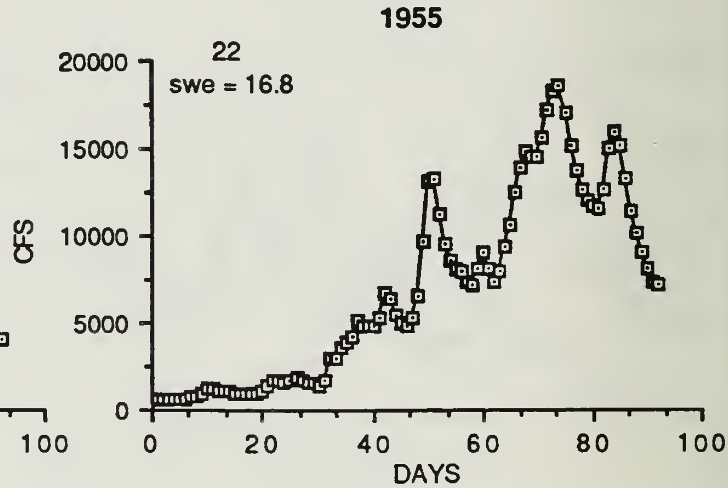
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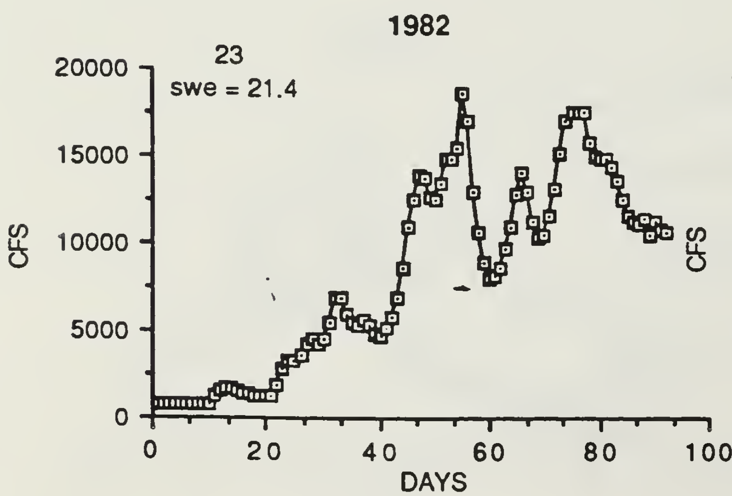
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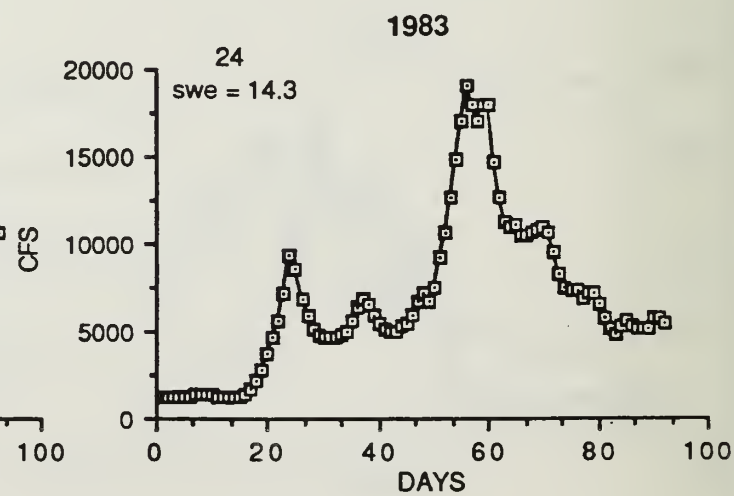
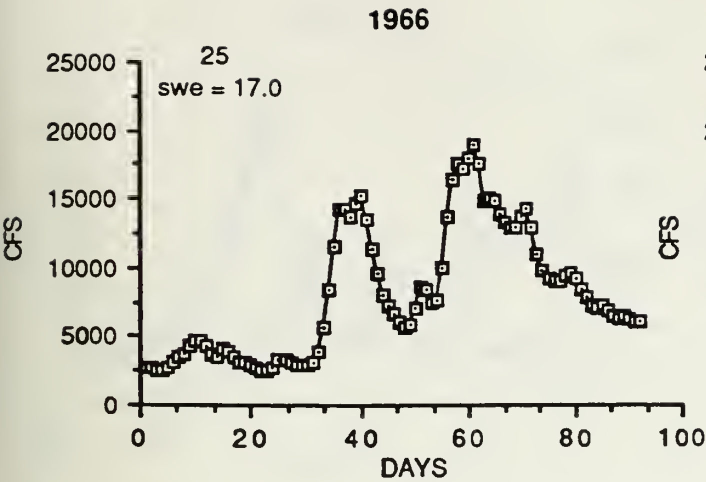
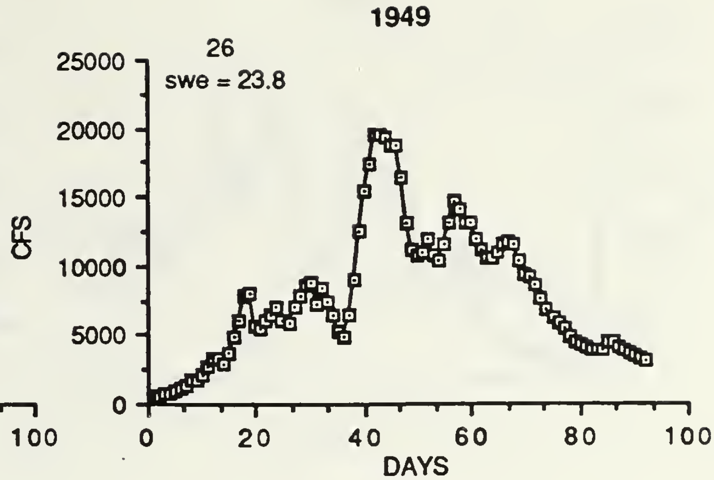
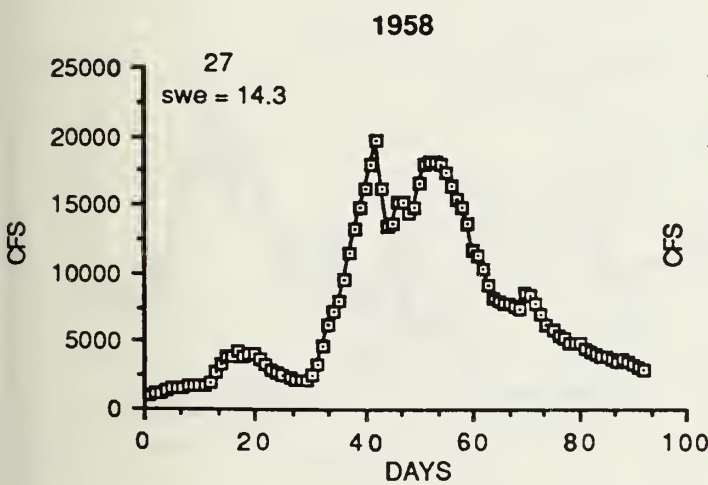
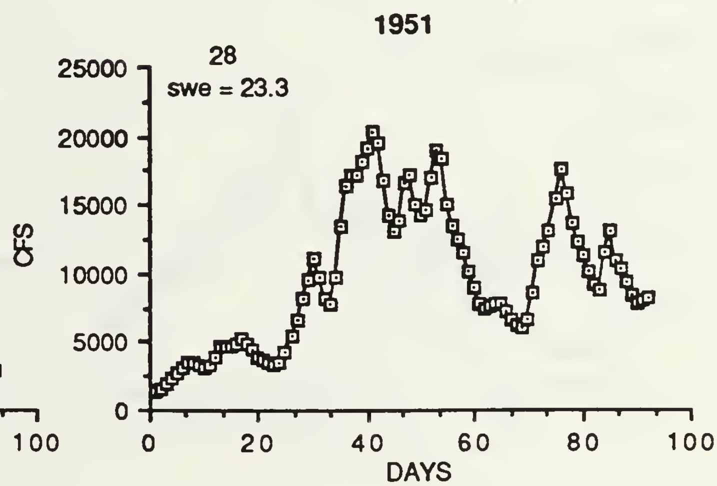
15000
20000
0
20
40
60
80
100

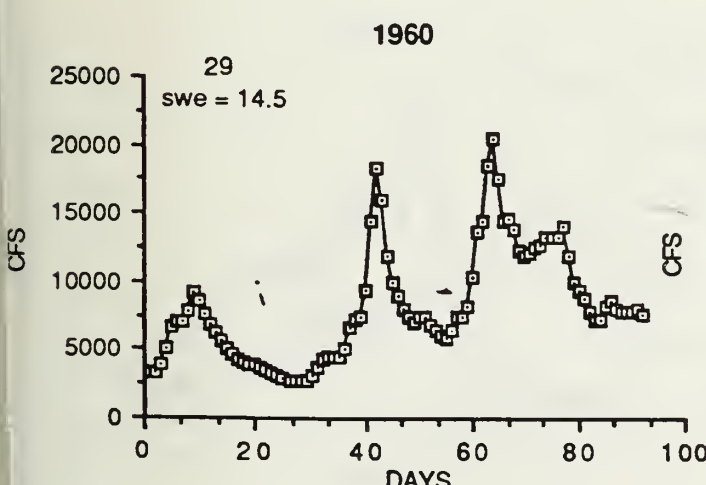

1983
24
swe = 14.3
CFS
DAYS
0
5000
10000
15000
20000
0
20
40
60
80
100

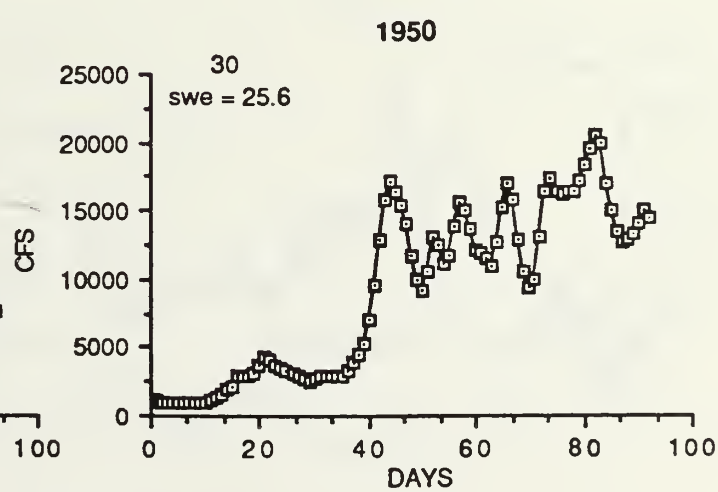

1966
25
swe = 17.0
CFS
DAYS

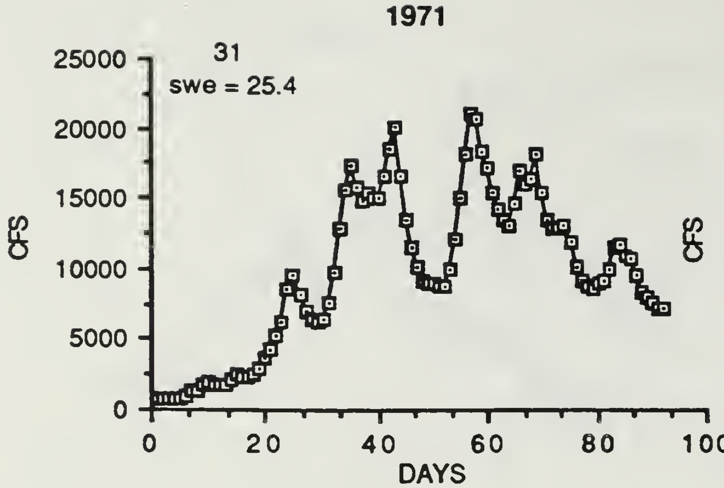

1949
26
swe = 23.8
CFS
DAYS

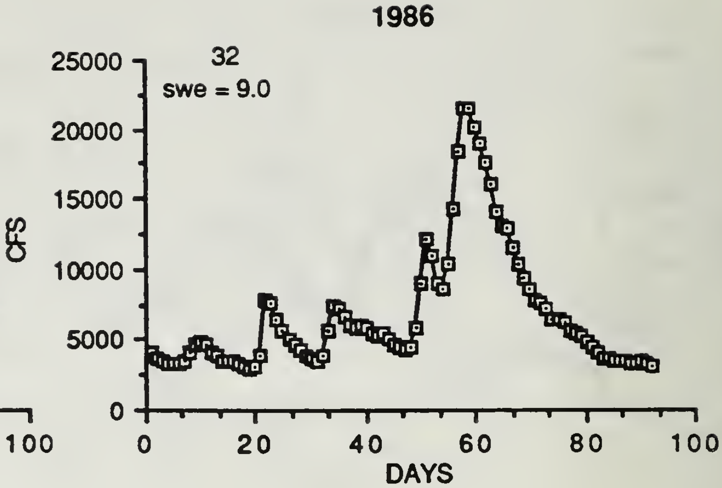

1958
27
swe = 14.3
CFS
DAYS

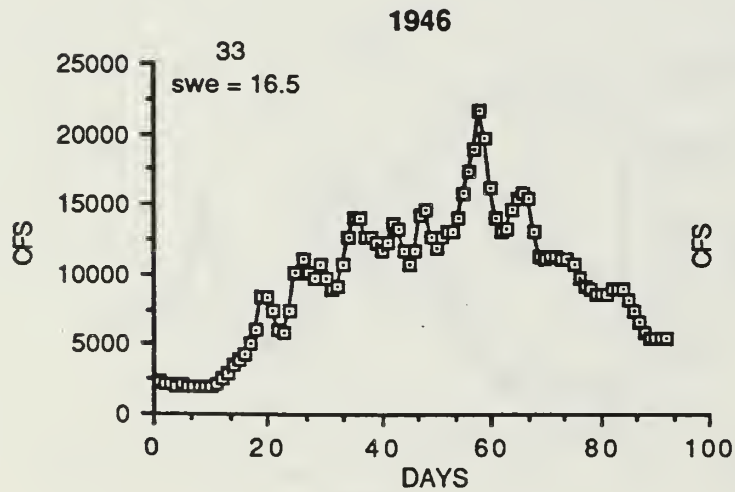

1951
28
swe = 23.3
CFS
DAYS

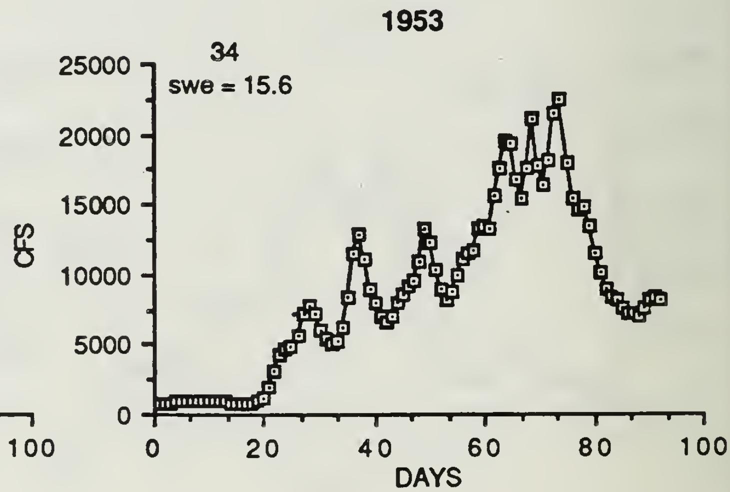

1960
29
swe = 14.5
CFS
DAYS

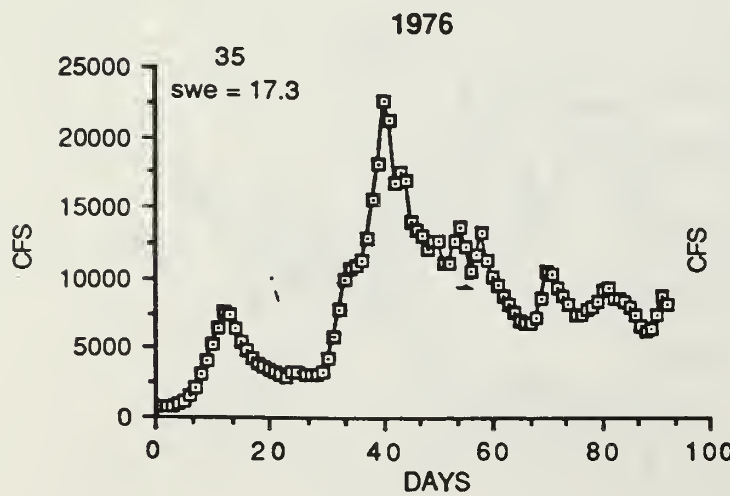

1950
30
swe = 25.6
CFS
DAYS

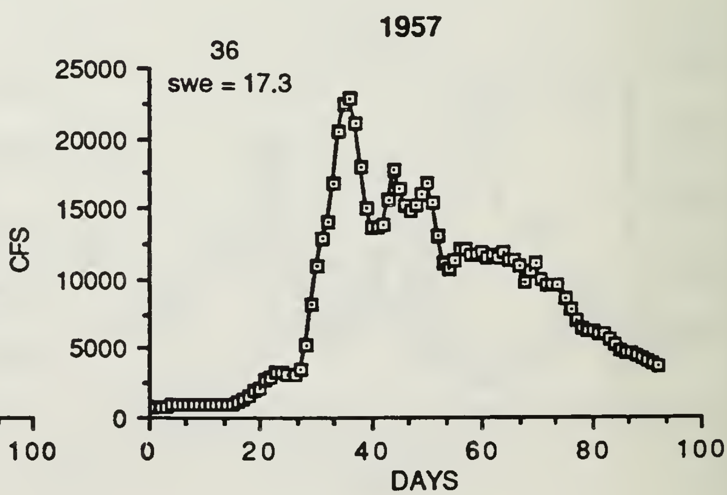

1971
31
swe = 25.4
CFS
DAYS

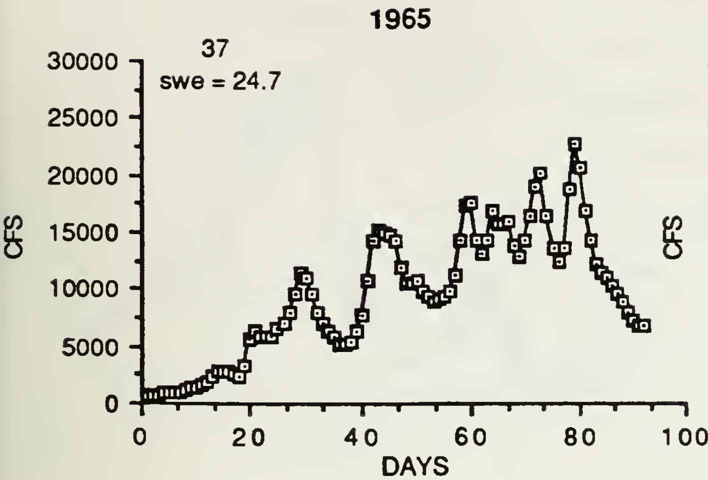

1986
32
swe = 9.0
CFS
DAYS

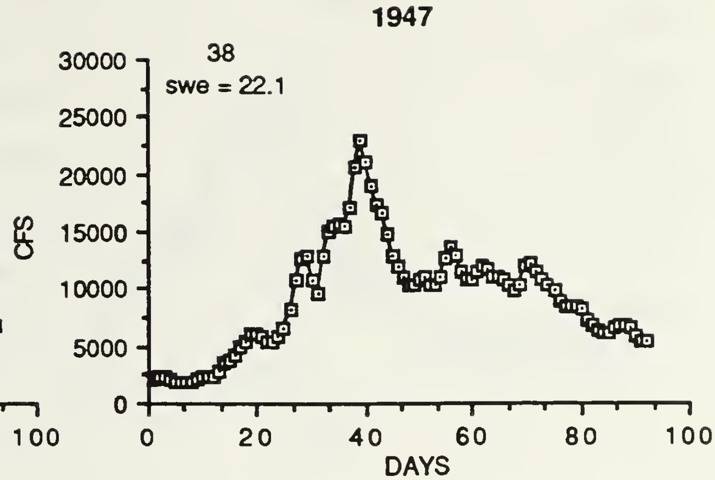

1946
33
swe = 16.5
CFS
DAYS

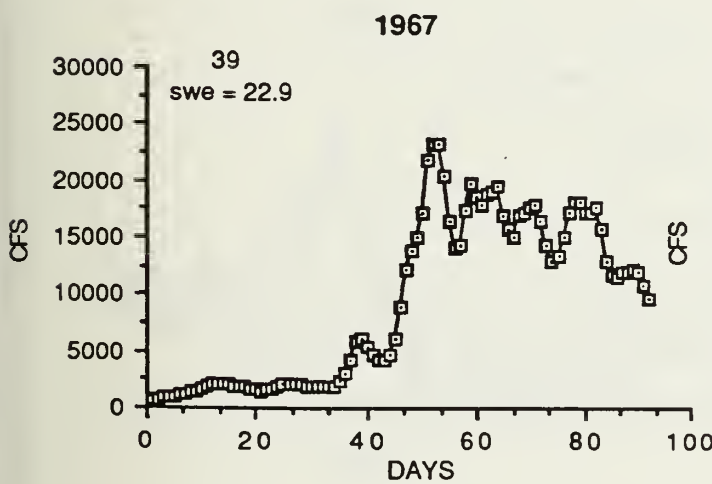

1953
34
swe = 15.6
CFS
DAYS

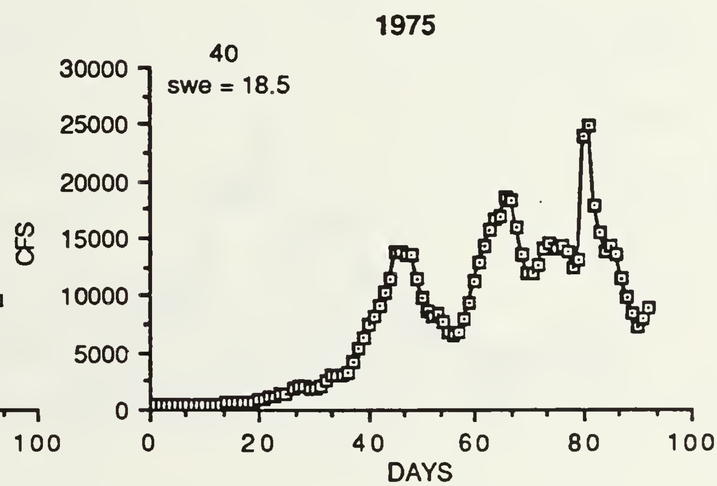

1976
35
swe = 17.3
CFS
DAYS

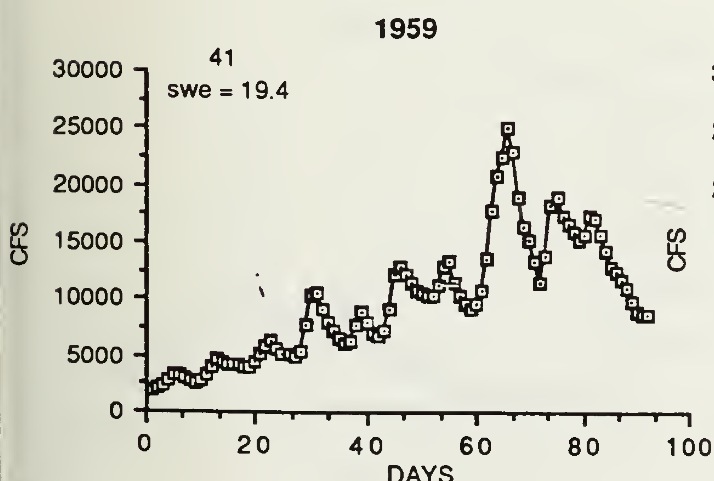

1957
36
swe = 17.3
CFS
DAYS

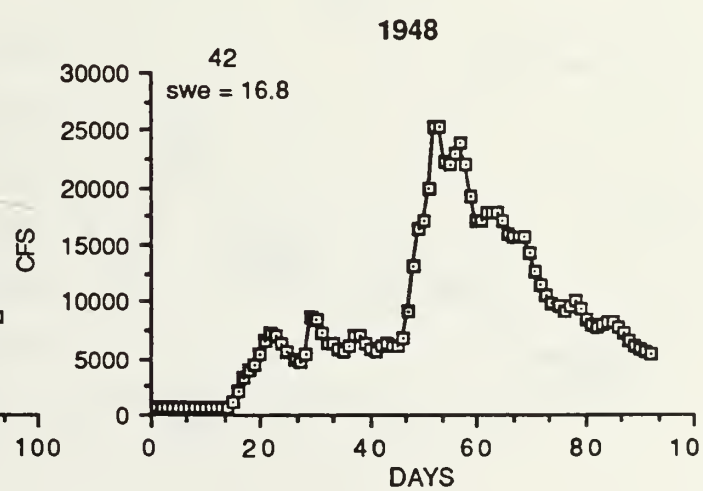

1965
37
swe = 24.7
CFS
DAYS

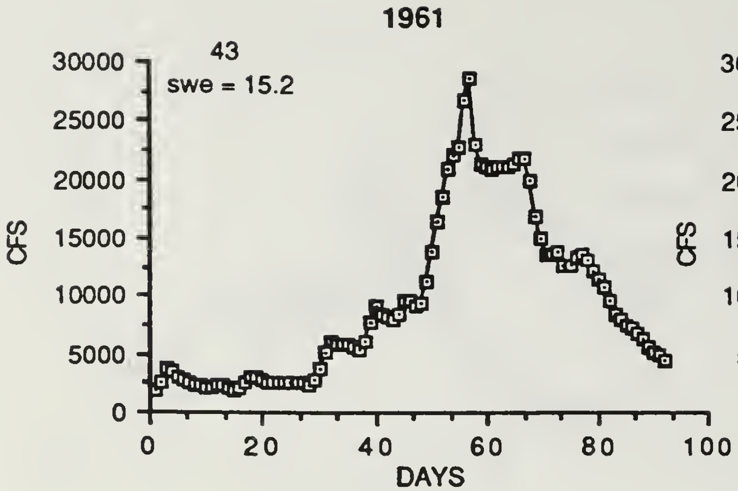

1947
38
swe = 22.1
CFS
DAYS

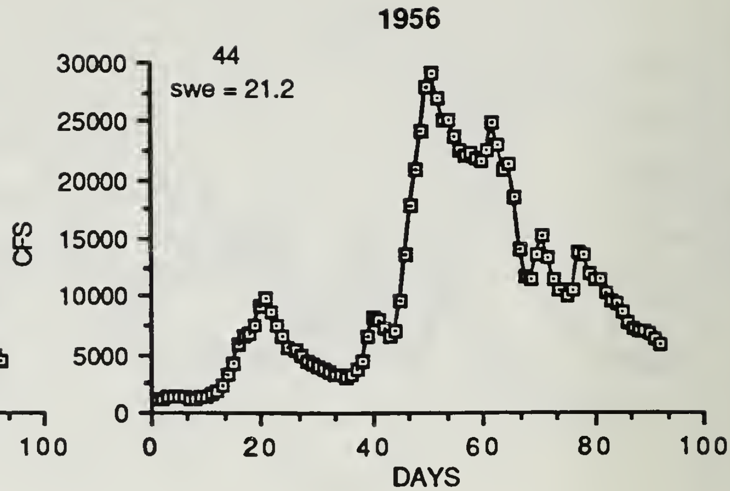

1967
39
swe = 22.9
CFS
DAYS

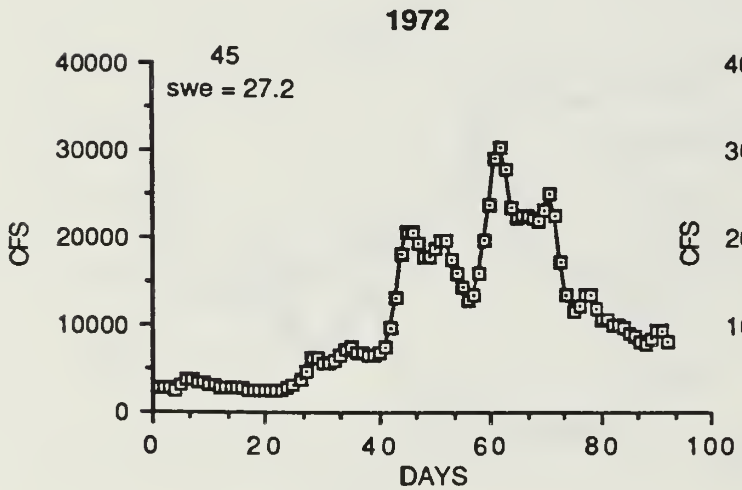

1975
40
swe = 18.5
CFS
DAYS

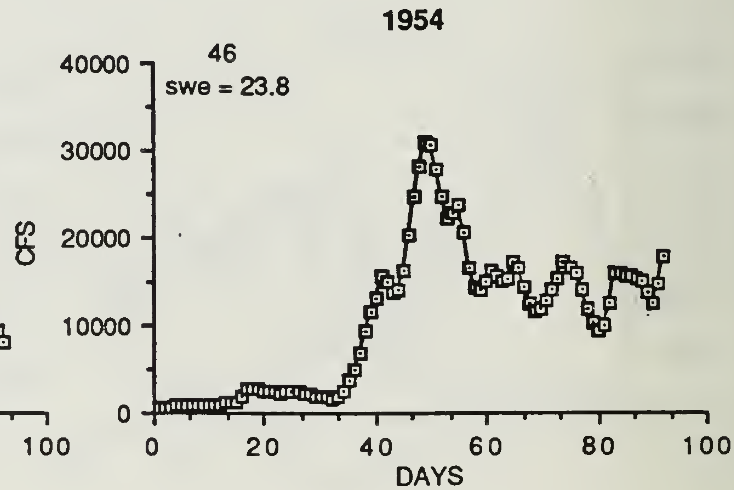

1959
41
swe = 19.4
CFS
DAYS

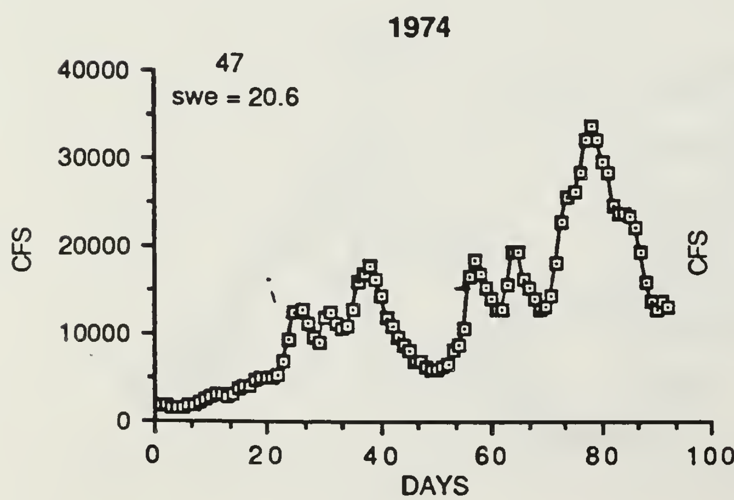

1948
42
swe = 16.8
CFS
DAYS

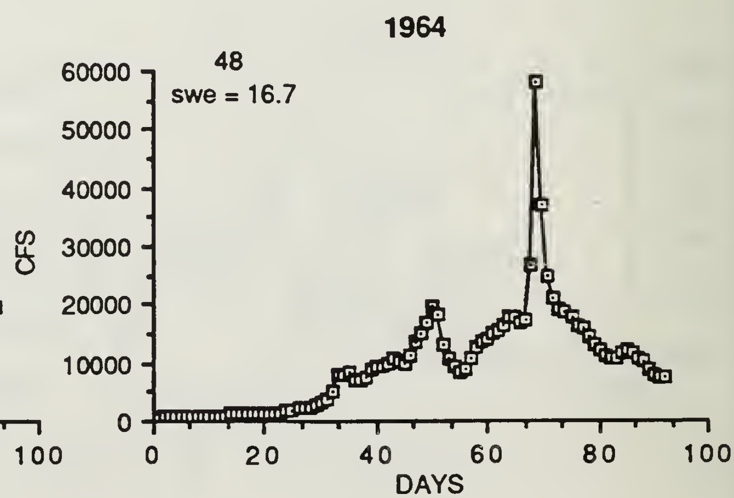

1961
43
swe = 15.2
CFS
DAYS
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100


1956
44
swe = 21.2
CFS
DAYS
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100

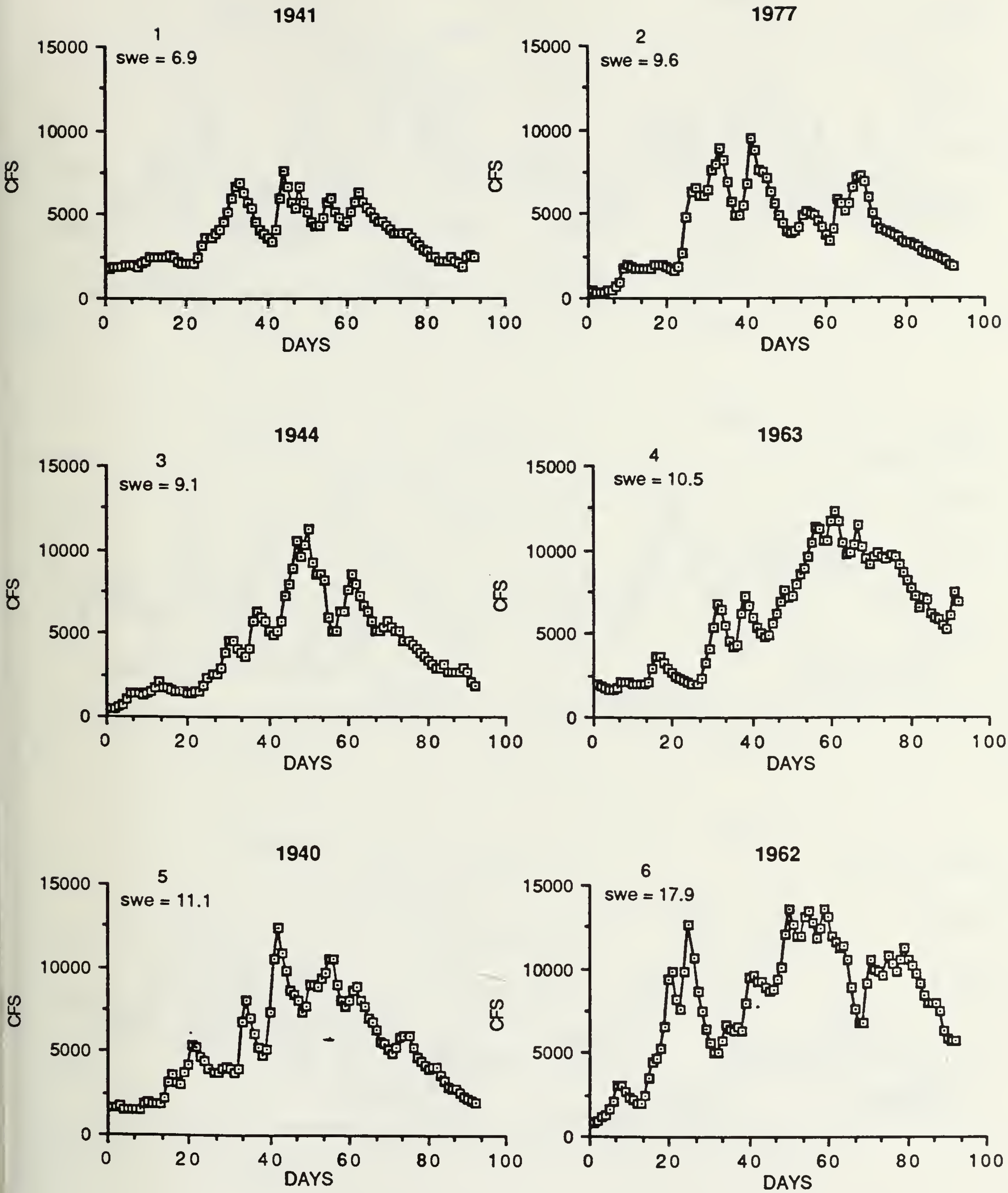

1972
45
swe = 27.2
CFS
DAYS
40000
30000
20000
10000
0
0
20
40
60
80
100

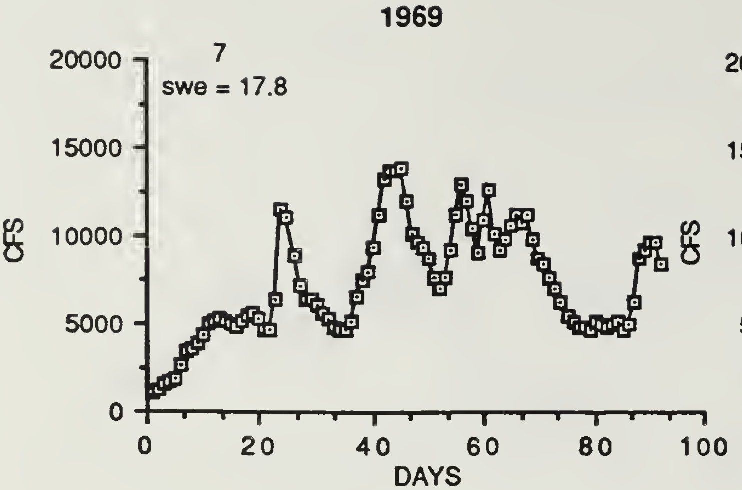

1954
46
swe = 23.8
CFS
DAYS
40000
30000
20000
10000
0
0
20
40
60
80
100

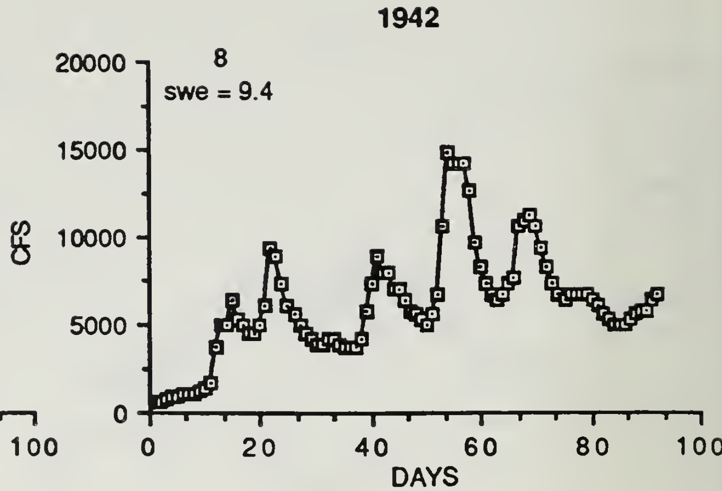

1974
47
swe = 20.6
CFS
DAYS
40000
30000
20000
10000
0
0
20
40
60
80
100

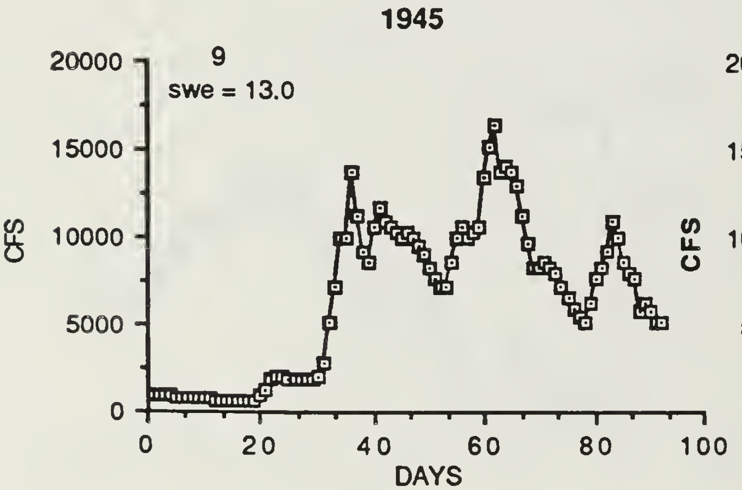

1964
48
swe = 16.7
CFS
DAYS
60000
50000
40000
30000
20000
10000
0
0
20
40
60
80
100

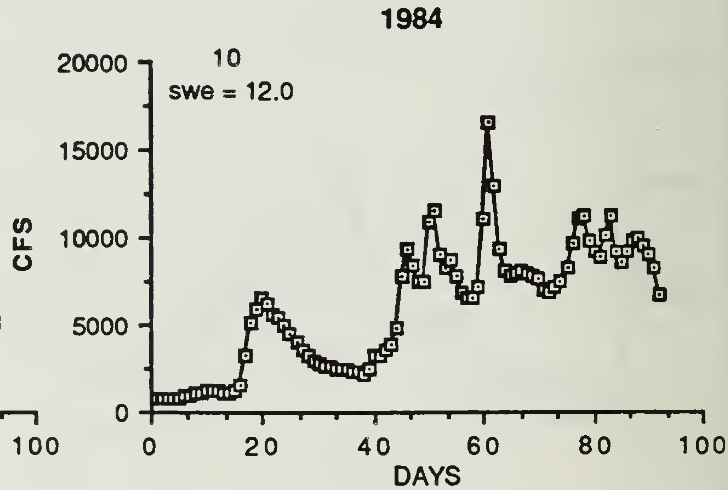
Appendix A2. Discharge patterns of the spring runoff (April 1 through June 30) in the Middle Fork of the Flathead River ranked by year of maximum discharge from 1940 - 1986.

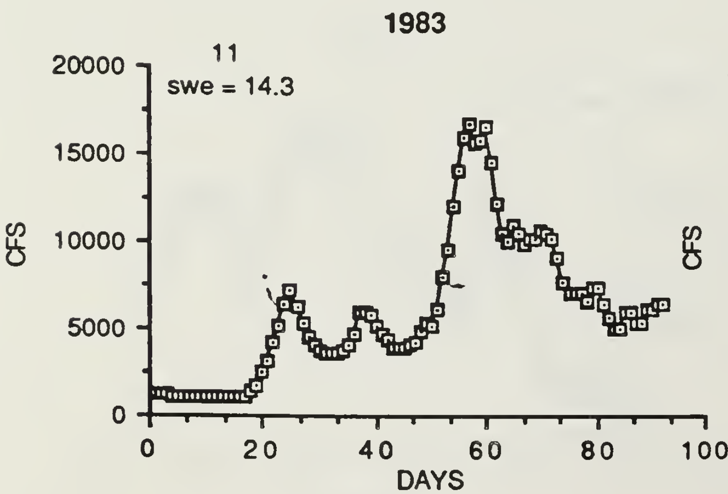

1941
1
swe = 6.9
1977
2
swe = 9.6
1944
3
swe = 9.1
1963
4
swe = 10.5
1940
5
swe = 11.1
1962
6
swe = 17.9
CFS
DAYS
0
5000
10000
15000
20
40
60
80
100

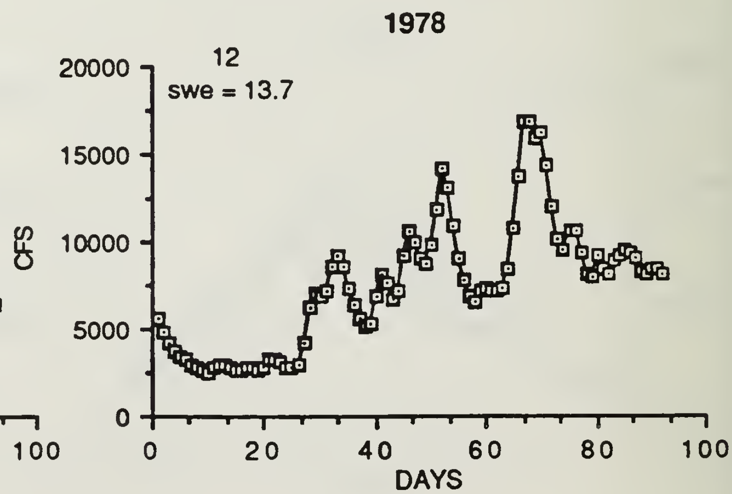

1969
7
swe = 17.8
CFS
DAYS

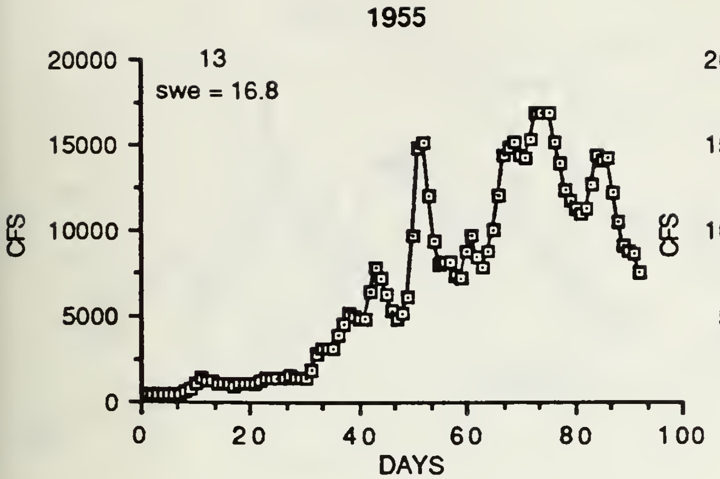

1942
8
swe = 9.4
CFS
DAYS

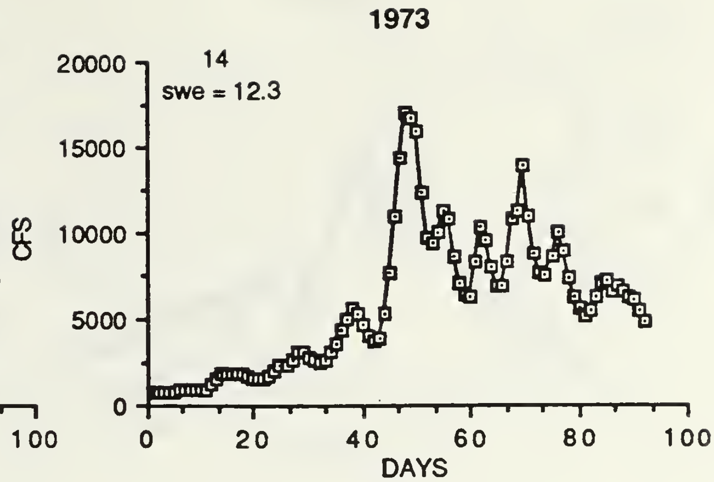

1945
9
swe = 13.0
CFS
DAYS

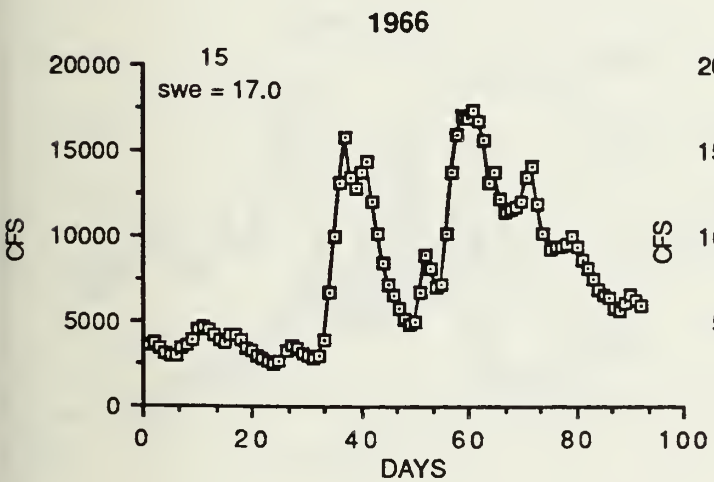

1984
10
swe = 12.0
CFS
DAYS

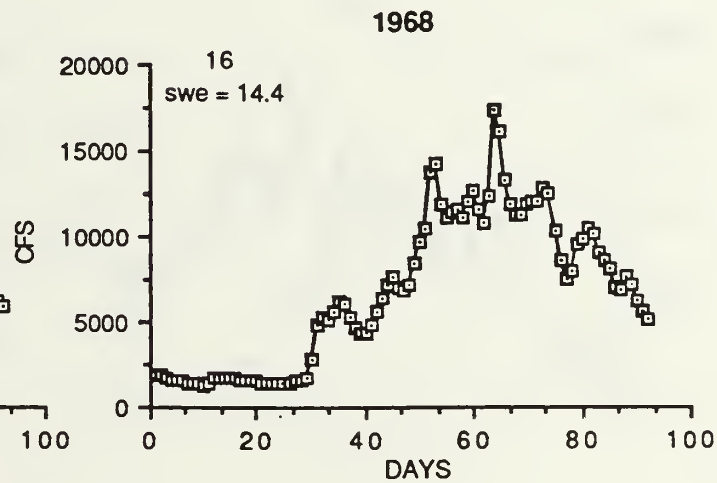

1983
11
swe = 14.3
CFS
DAYS

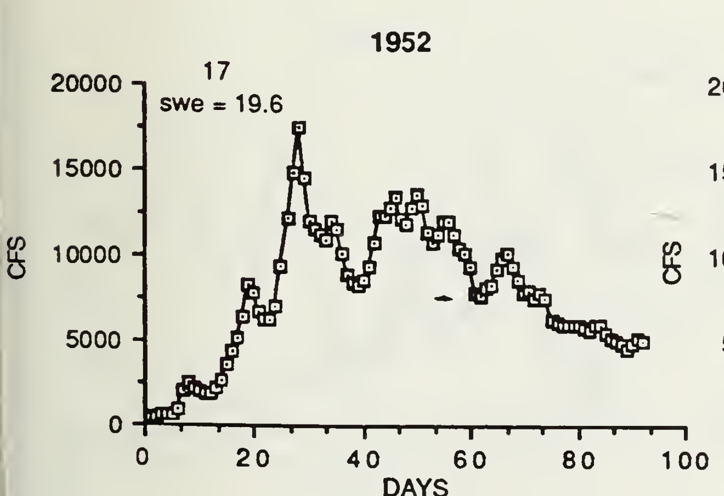

1978
12
swe = 13.7
CFS
DAYS

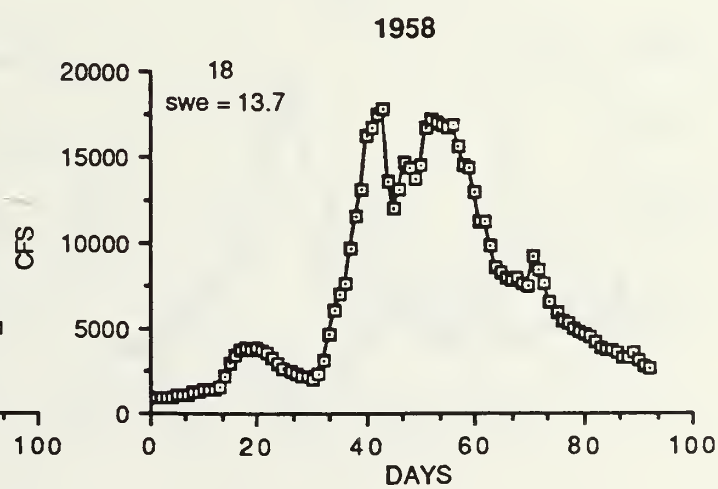

1955
13
swe = 16.8
CFS
DAYS

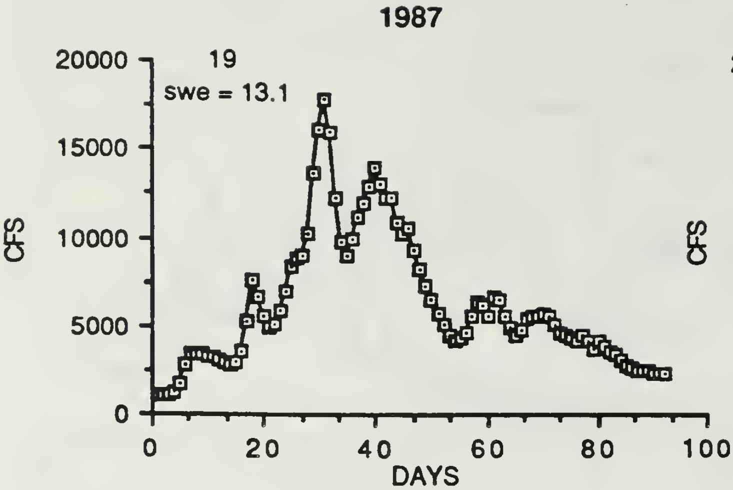

1973
14
swe = 12.3
CFS
DAYS

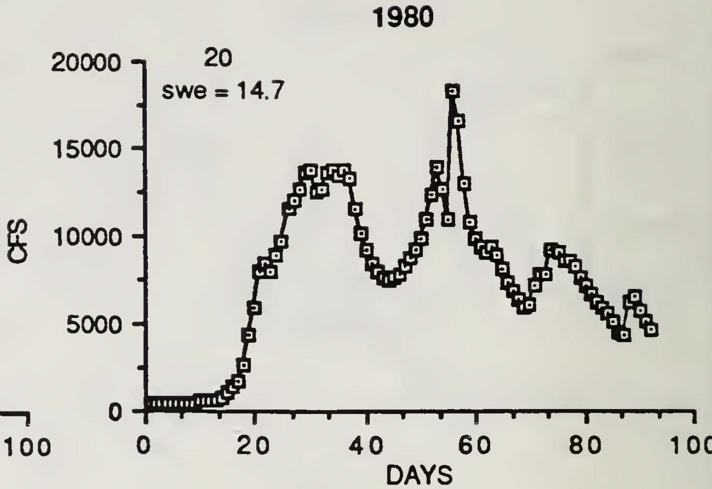

1966
15
swe = 17.0
CFS
DAYS

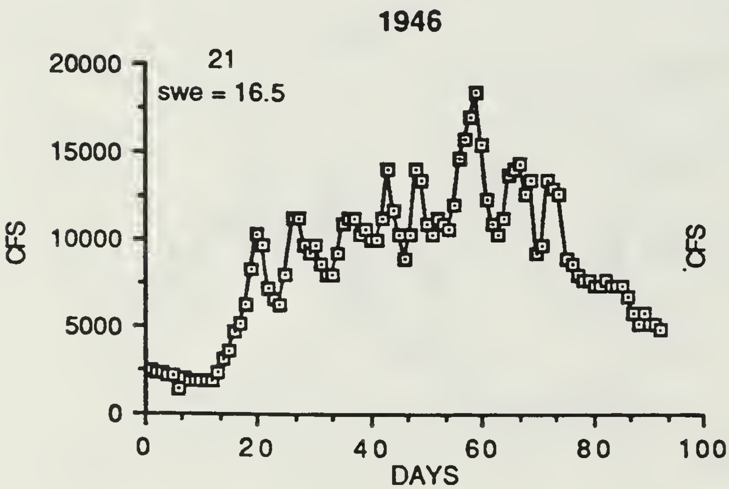

1968
16
swe = 14.4
CFS
DAYS

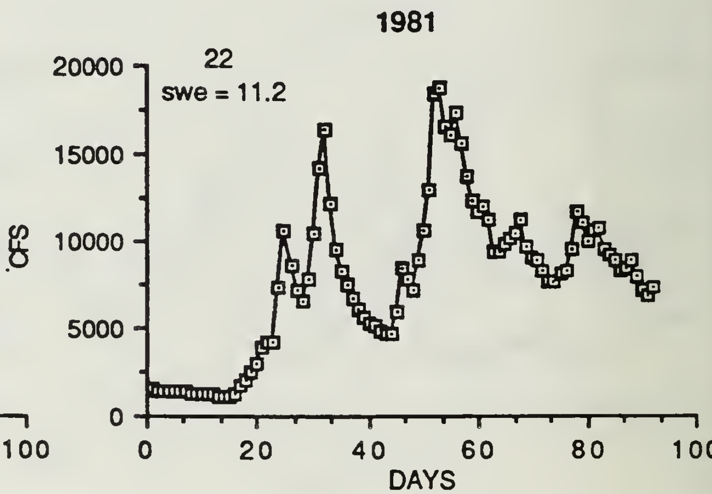

1952
17
swe = 19.6
CFS
DAYS

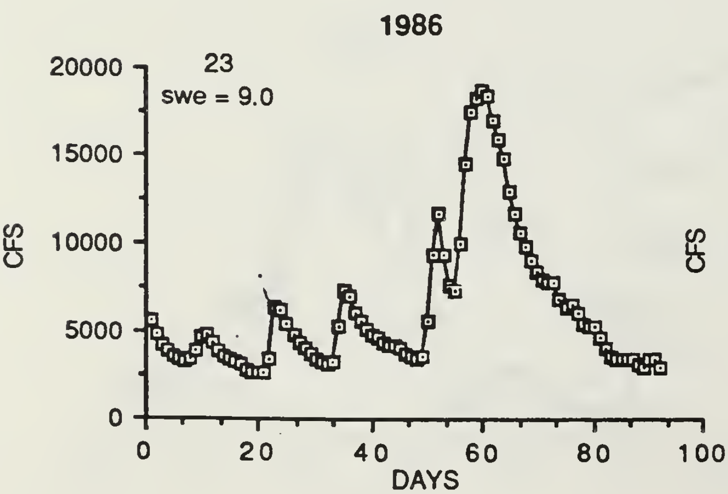

1958
18
swe = 13.7
CFS
DAYS

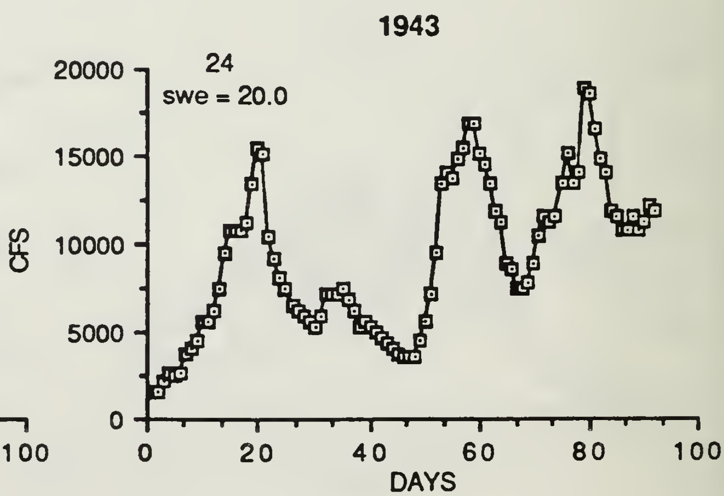

1987
19
swe = 13.1
CFS
DAYS

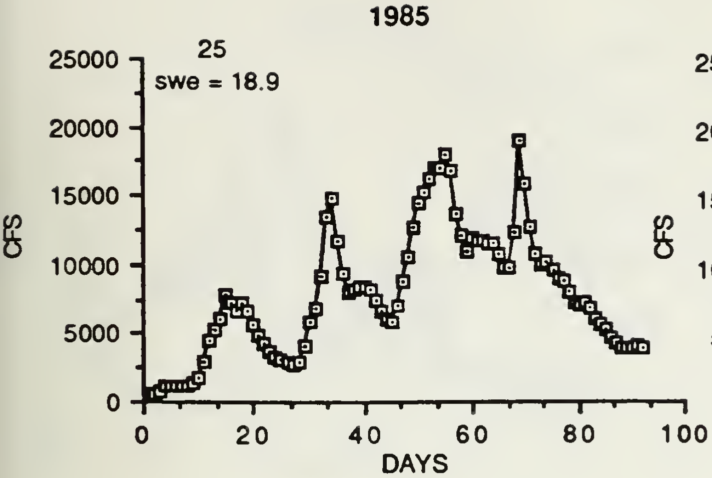

1980
20
swe = 14.7
CFS
DAYS

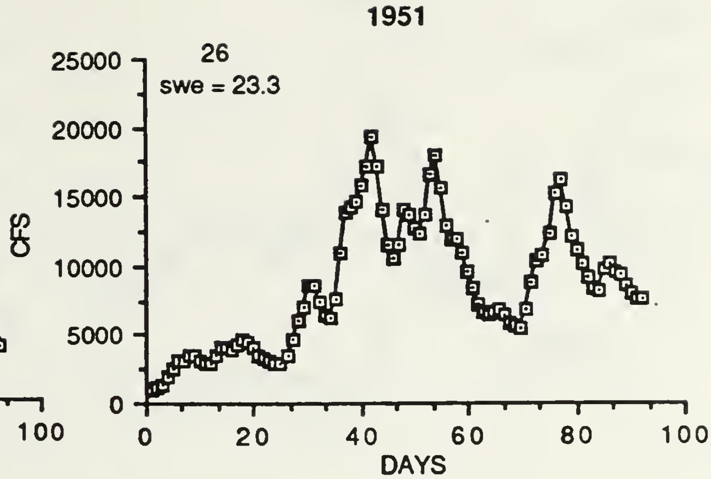

1946
21
swe = 16.5
CFS
DAYS

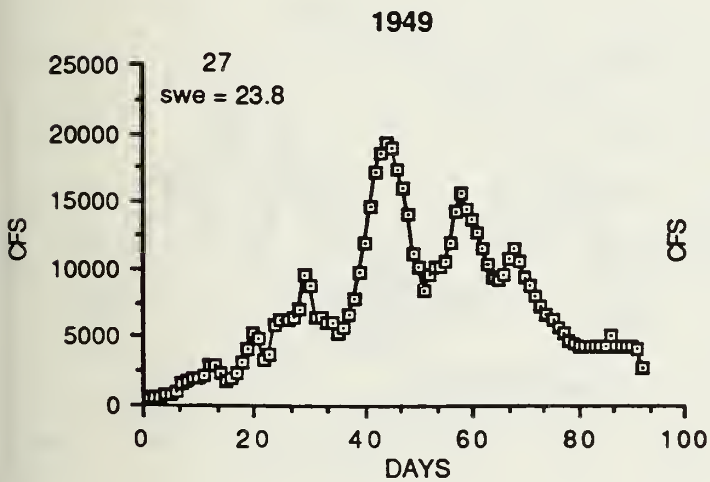

1981
22
swe = 11.2
CFS
DAYS

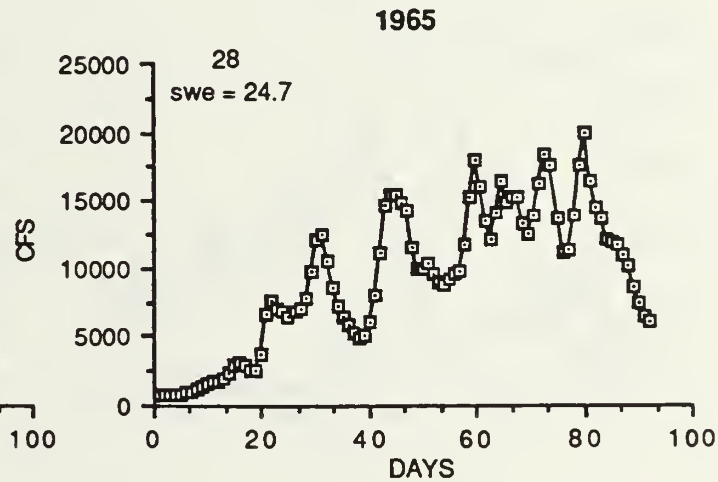

1986
23
swe = 9.0
CFS
DAYS

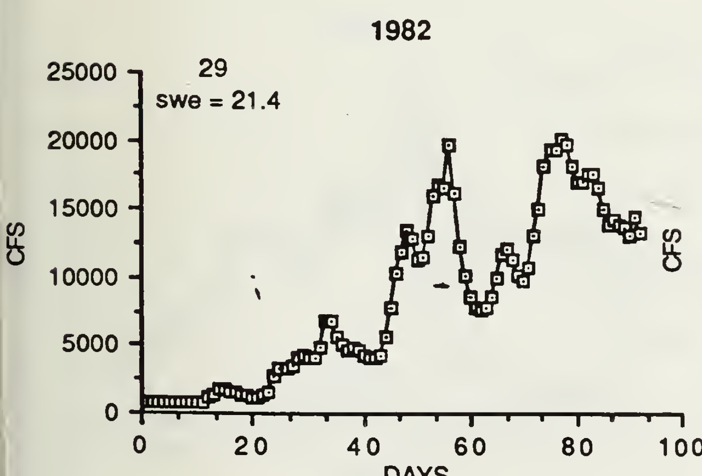

1943
24
swe = 20.0
CFS
DAYS

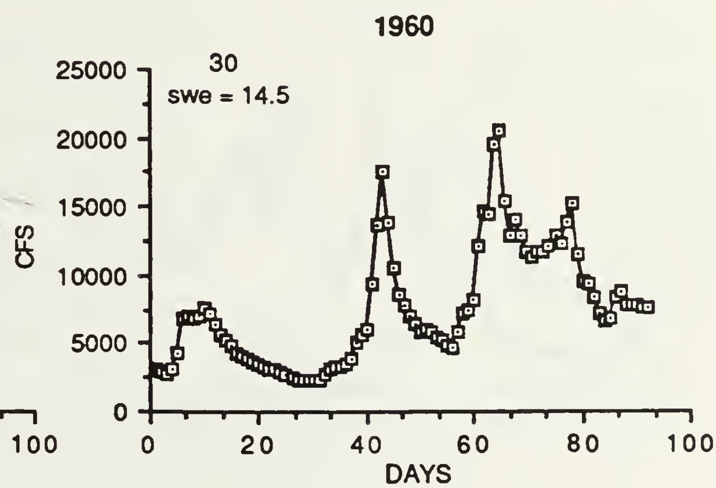

1985
25
swe = 18.9
CFS
DAYS

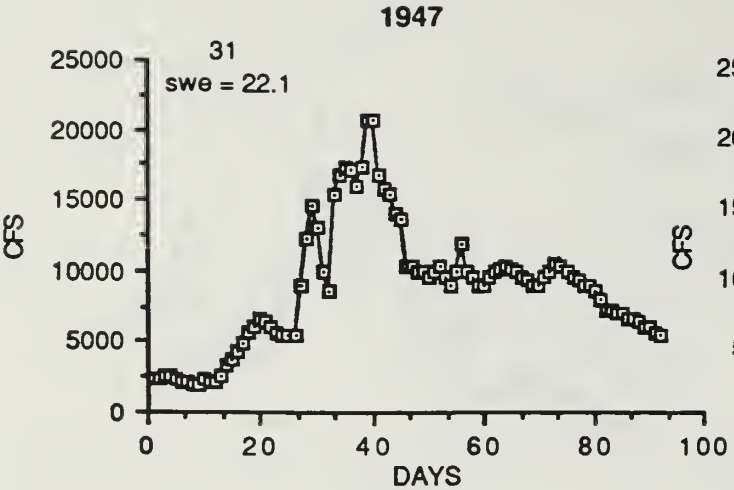

1951
26
swe = 23.3
CFS
DAYS

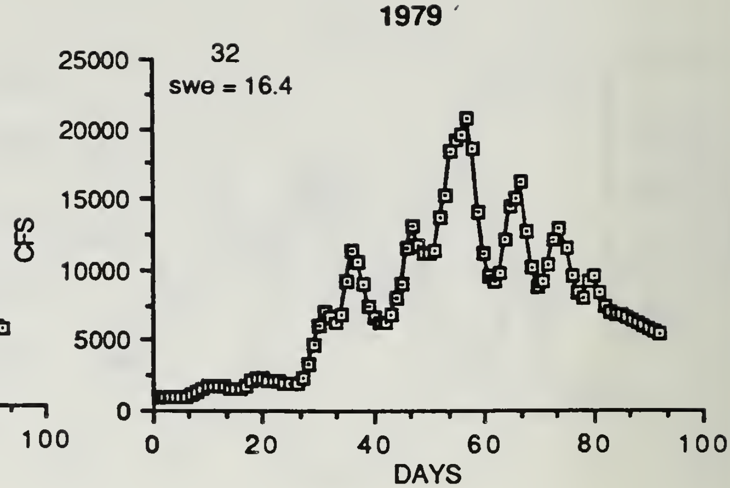

1949
27
swe = 23.8
CFS
DAYS

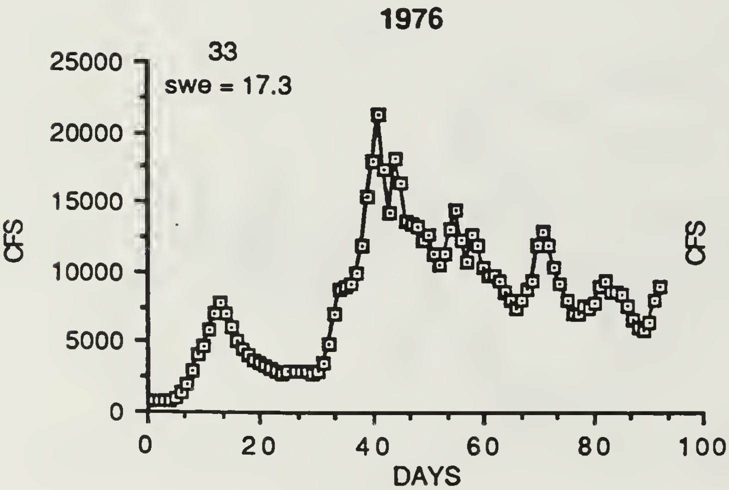

1965
28
swe = 24.7
CFS
DAYS

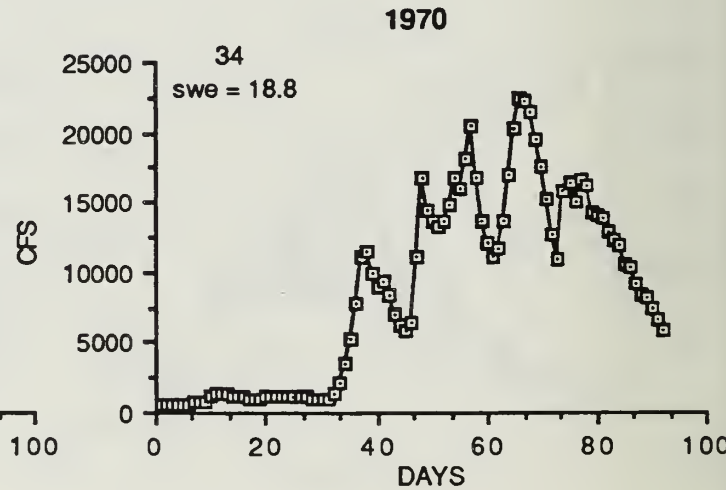

1982
29
swe = 21.4
CFS
DAYS

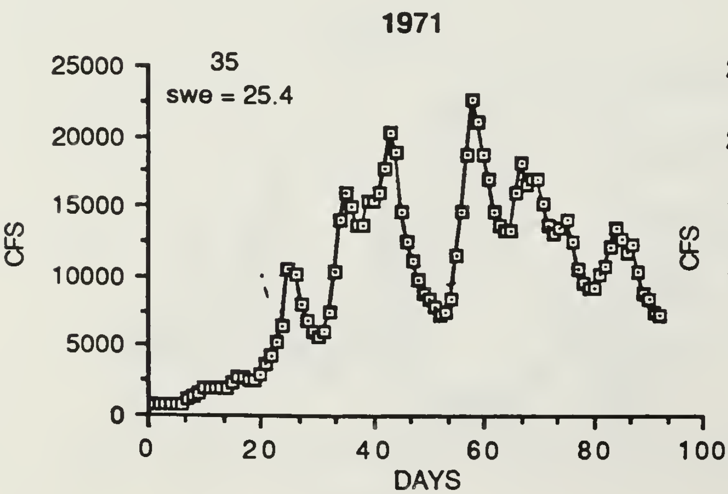

1960
30
swe = 14.5
CFS
DAYS

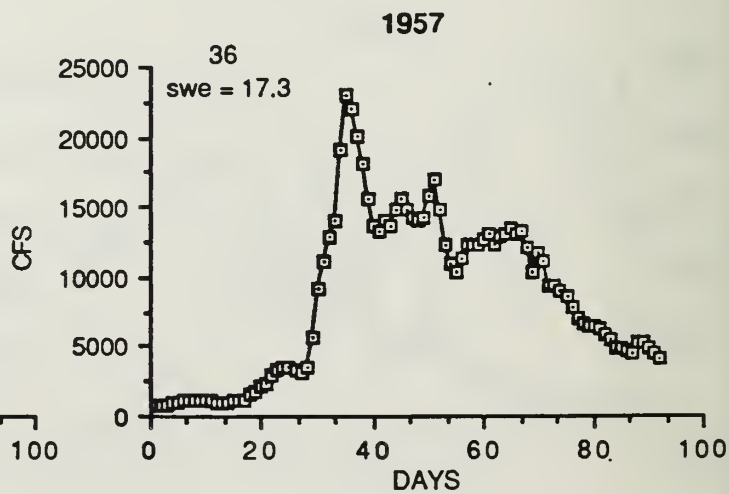

1947
31
swe = 22.1
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

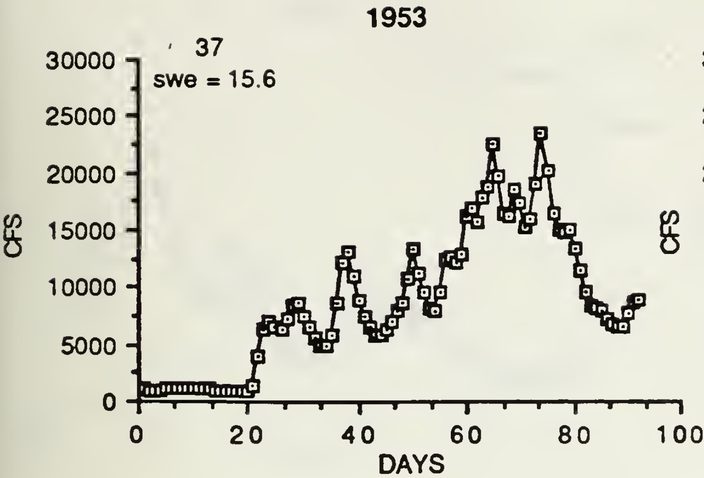

1979
32
swe = 16.4
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

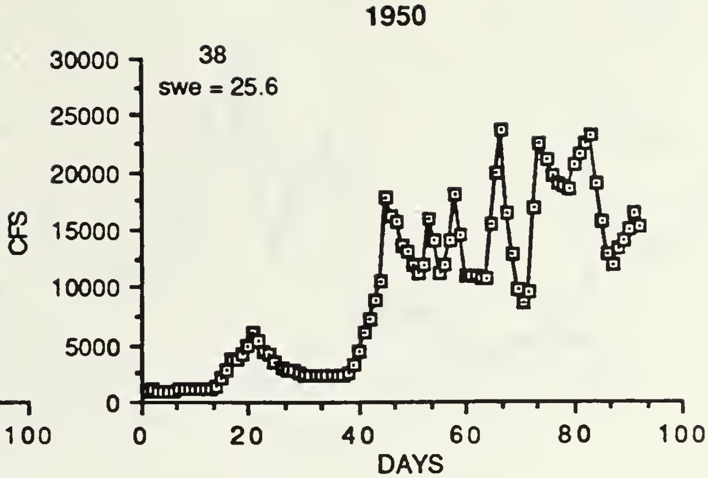

1976
33
swe = 17.3
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

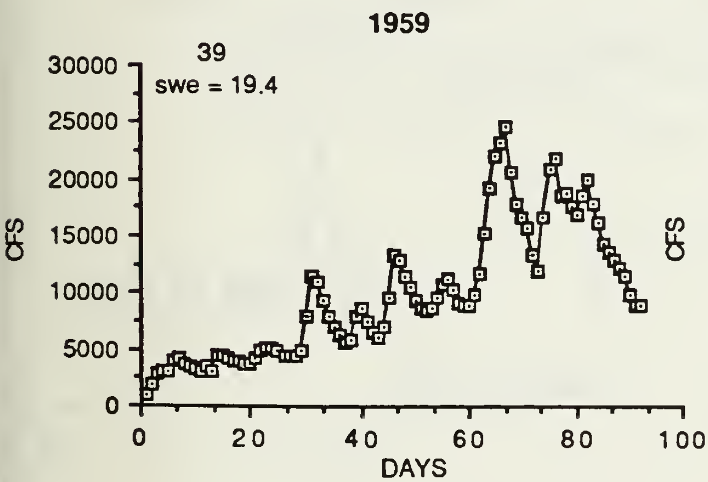

1970
34
swe = 18.8
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

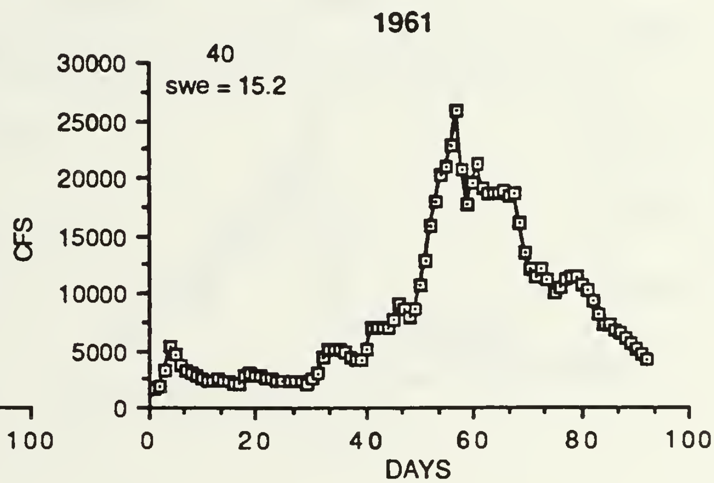

1971
35
swe = 25.4
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

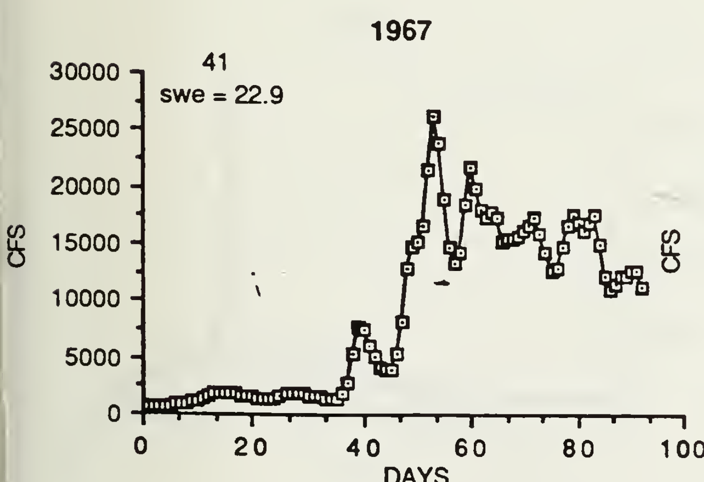

1957
36
swe = 17.3
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

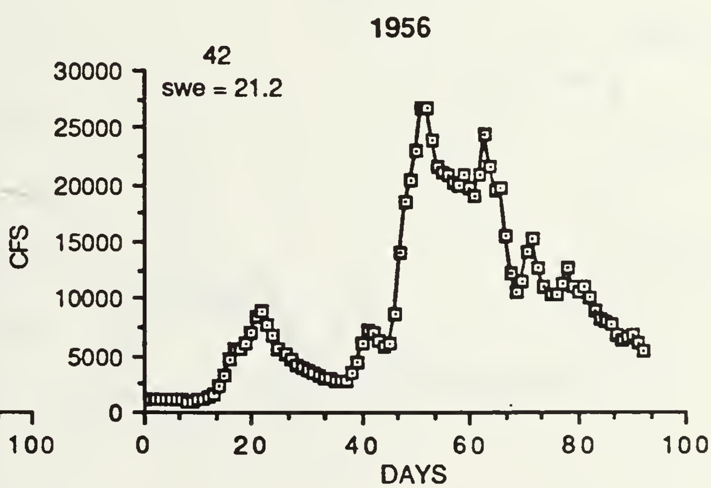

1953
37
swe = 15.6
CFS
30000 25000 20000 15000 10000 5000 0
0 20 40 60 80 100
DAYS

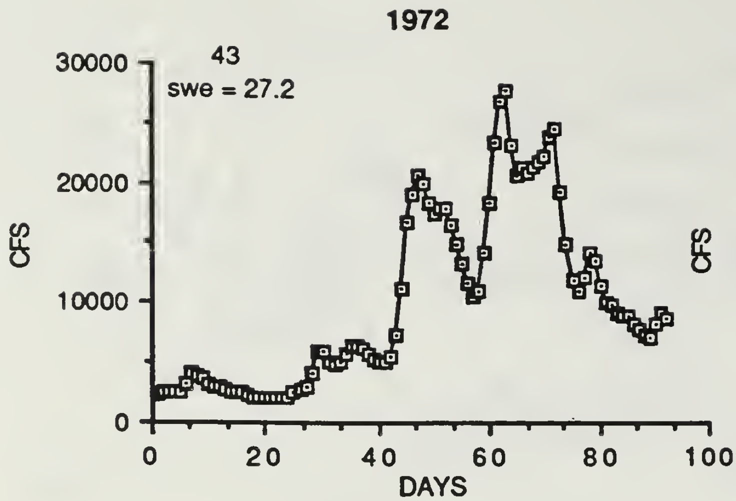

1950
38
swe = 25.6
CFS
30000 25000 20000 15000 10000 5000 0
0 20 40 60 80 100
DAYS

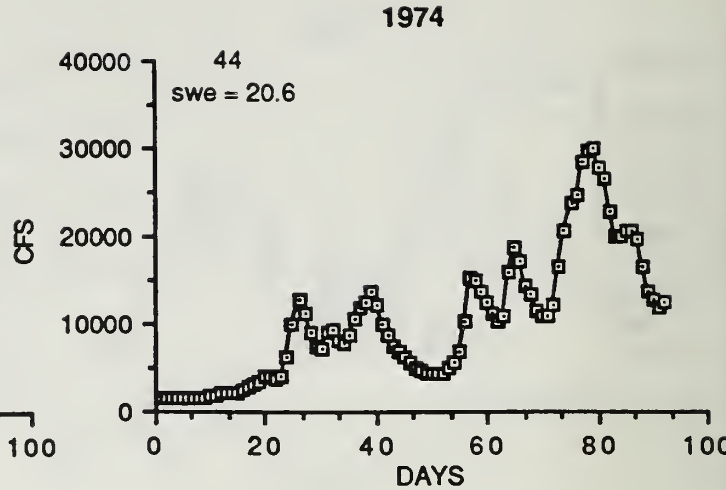

1959
39
swe = 19.4
CFS
30000 25000 20000 15000 10000 5000 0
0 20 40 60 80 100
DAYS

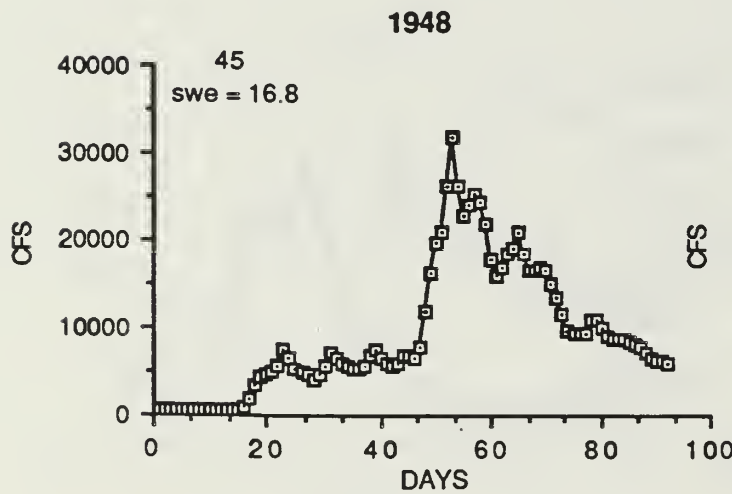

1961
40
swe = 15.2
CFS
30000 25000 20000 15000 10000 5000 0
0 20 40 60 80 100
DAYS

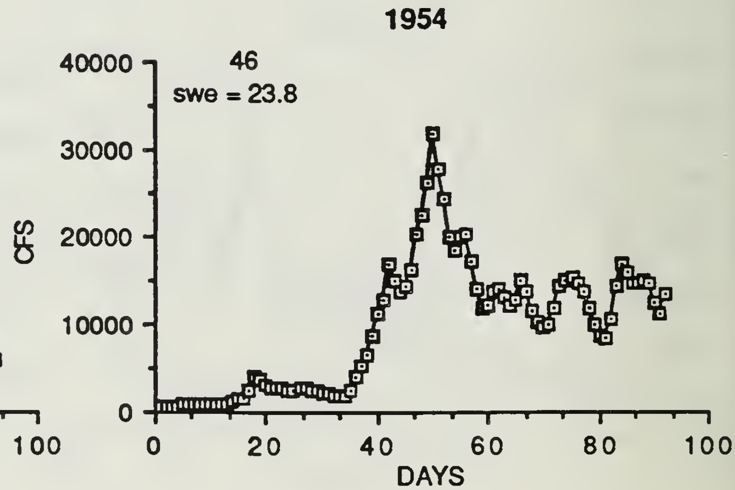

1967
41
swe = 22.9
CFS
30000 25000 20000 15000 10000 5000 0
0 20 40 60 80 100
DAYS

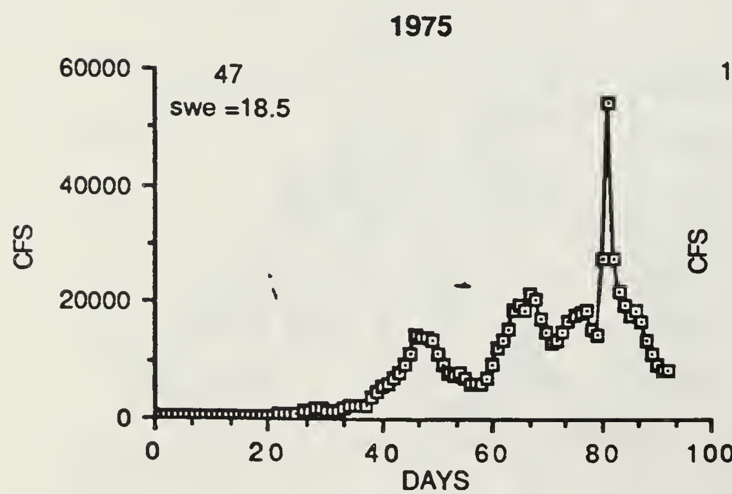

1956
42
swe = 21.2
CFS
30000 25000 20000 15000 10000 5000 0
0 20 40 60 80 100
DAYS

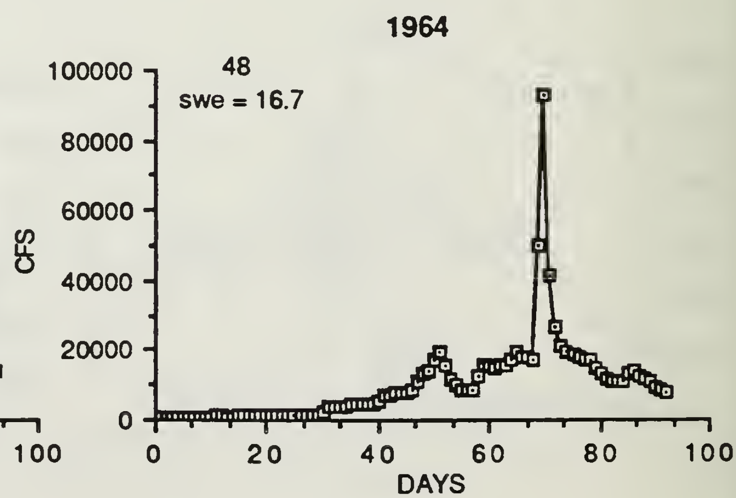

1972
43
swe = 27.2
CFS
DAYS


1974
44
swe = 20.6
CFS
DAYS


1948
45
swe = 16.8
CFS
DAYS


1954
46
swe = 23.8
CFS
DAYS

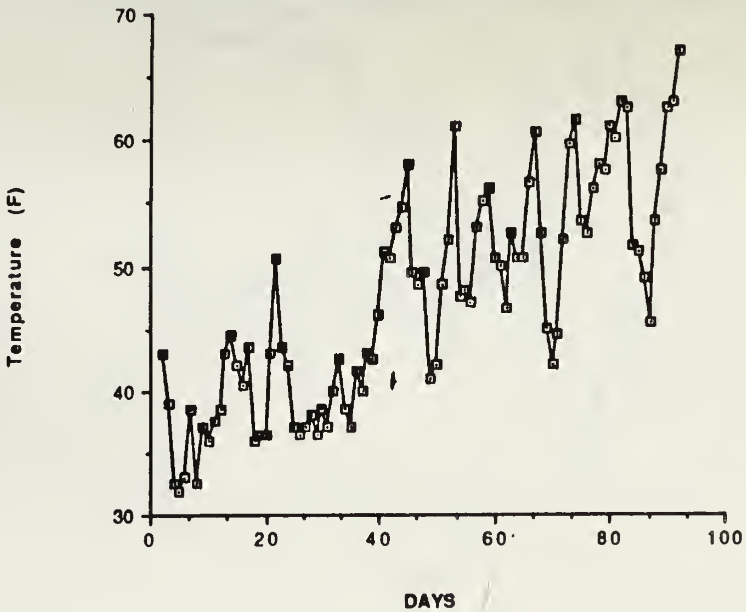

1975
47
swe =18.5
CFS
DAYS


1964
48
swe = 16.7
CFS
DAYS

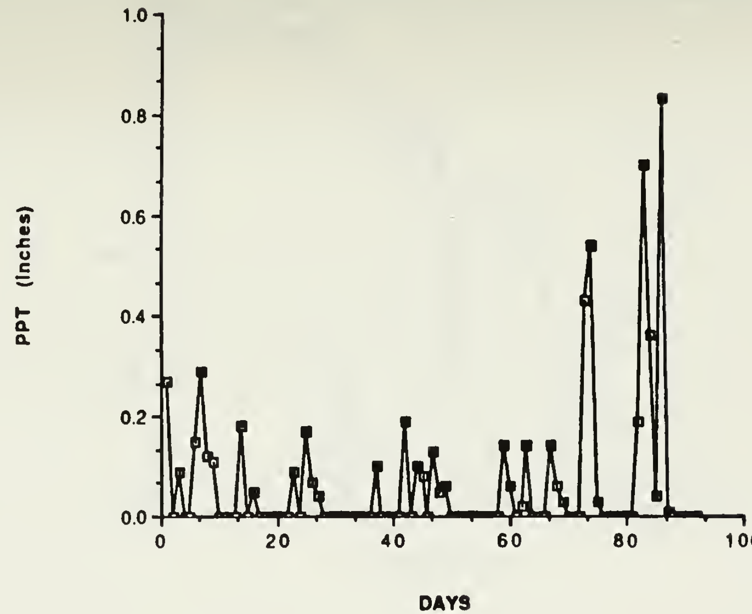
Appendix B. Selected years of temperature, precipitation and discharge at sites indicated, illustrating patterns and relationship of climatic conditions to spring runoff (April 1 through June 30).

1950

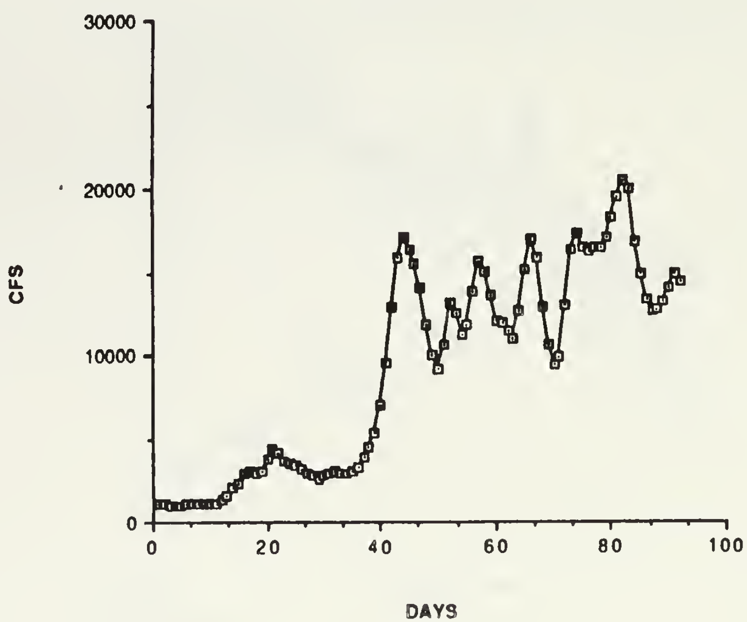
West Glacier



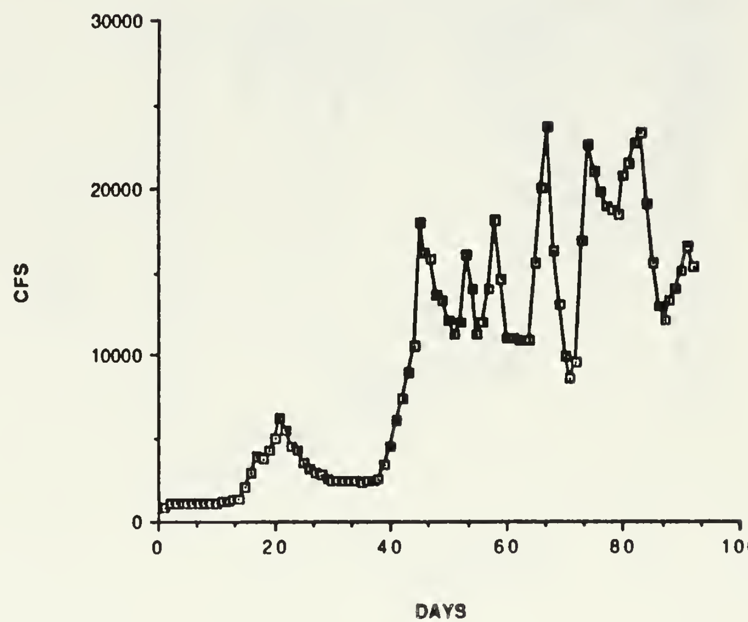
West Glacier



North Fork

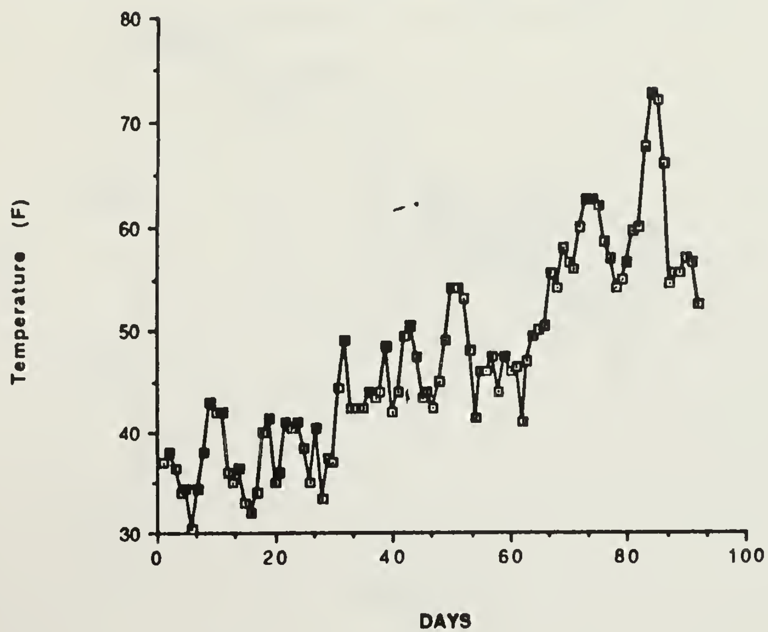


Middle Fork

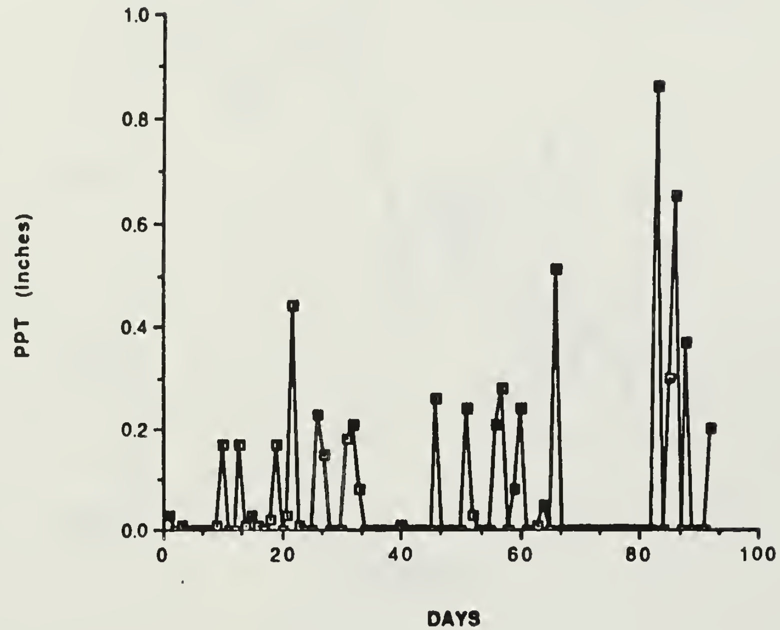


1955

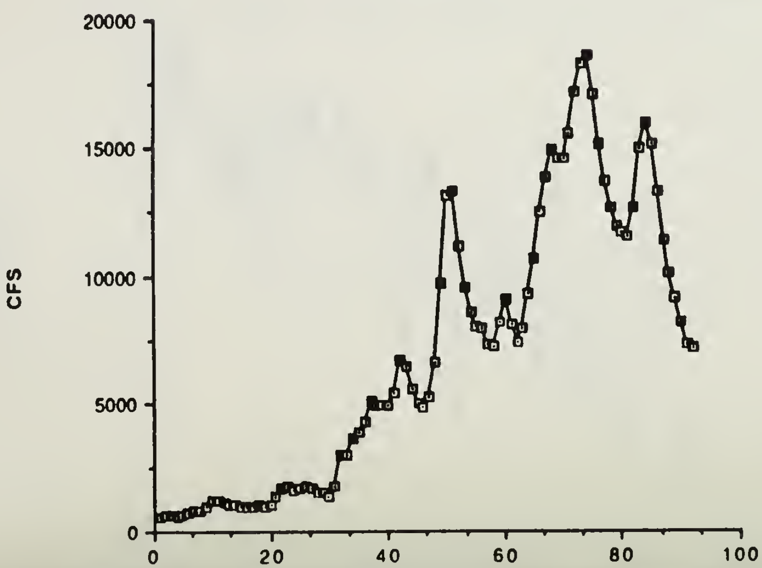
West Glacier



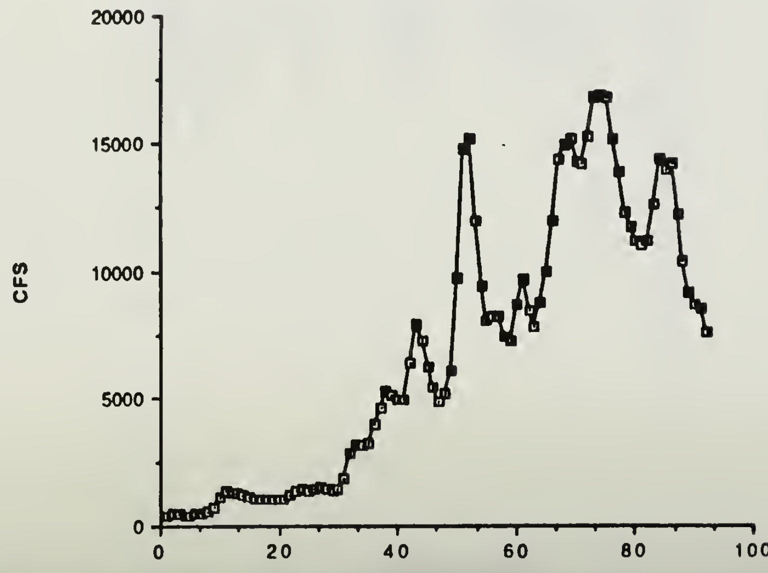
West Glacier



North Fork

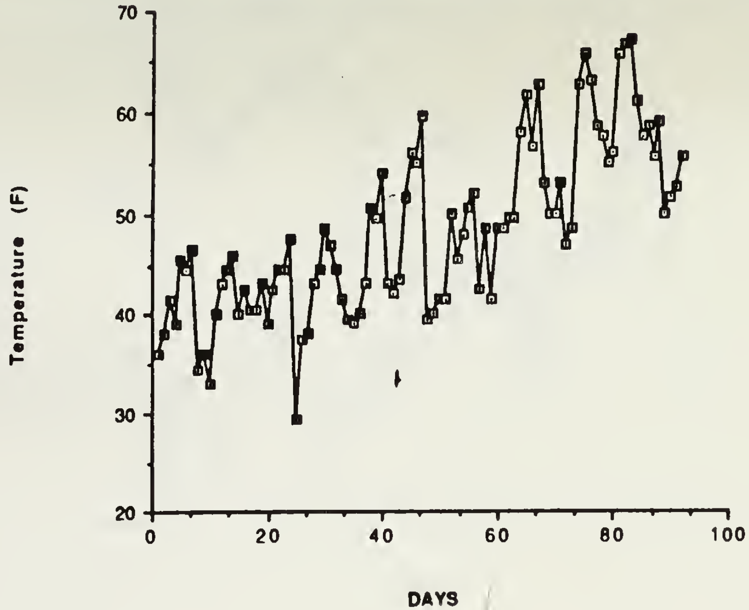


Middle Fork

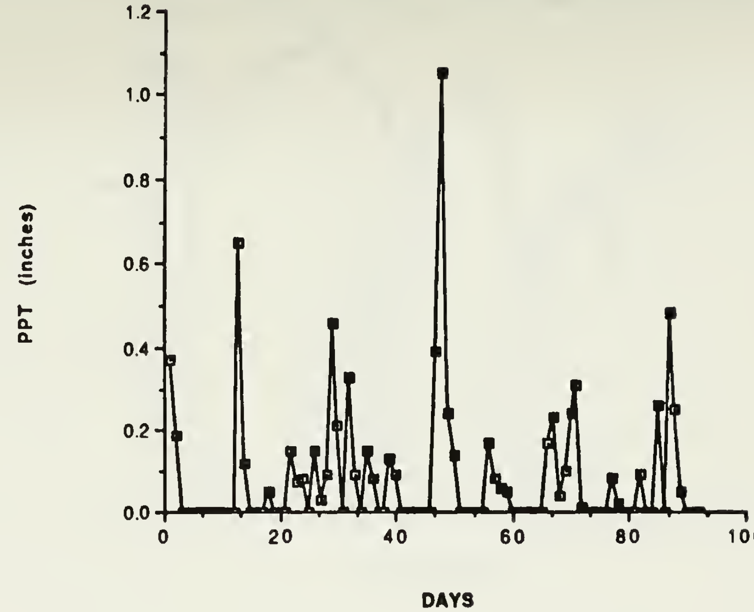


1959

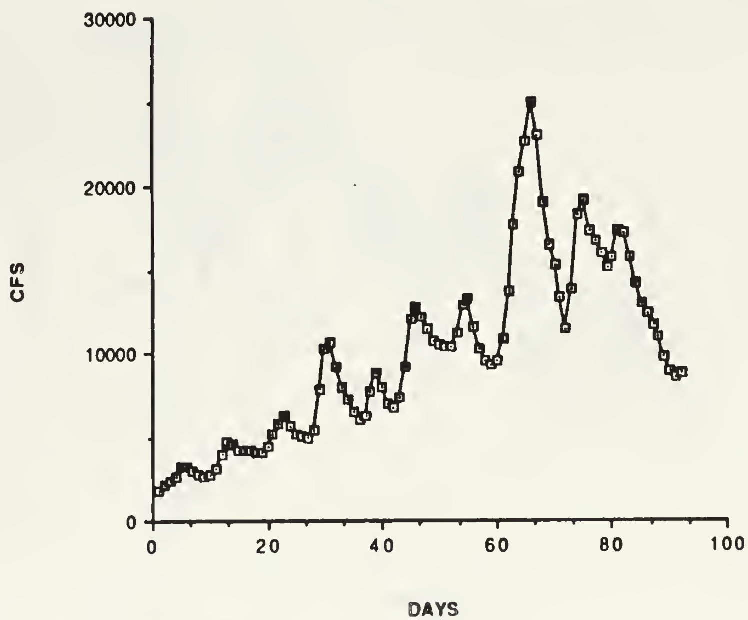
West Glacier



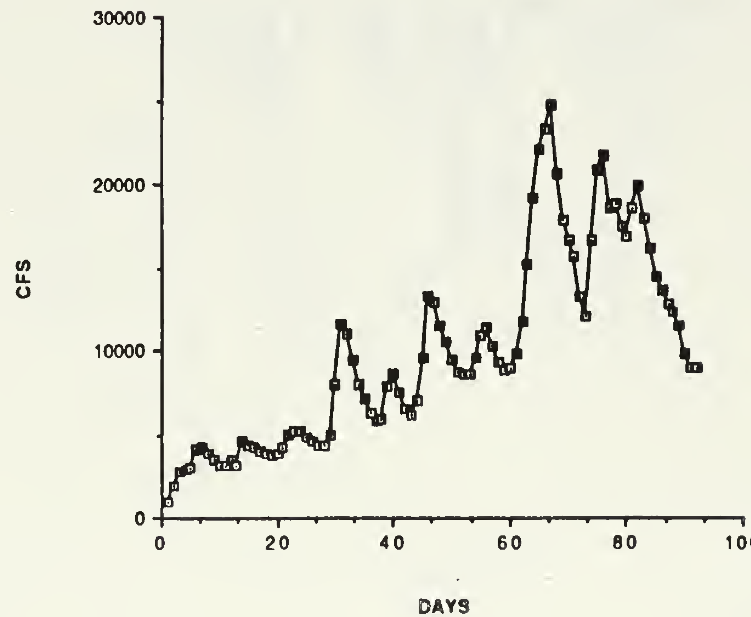
West Glacier



North Fork

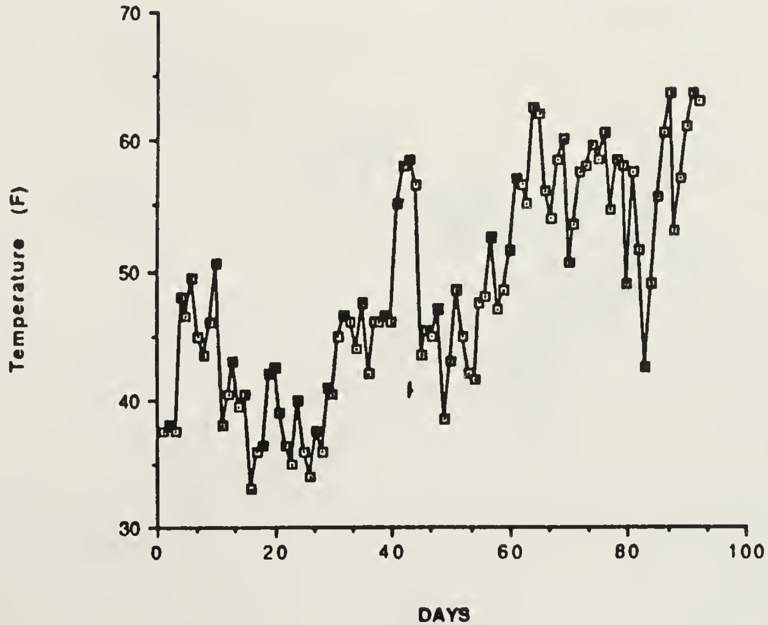


Middle Fork

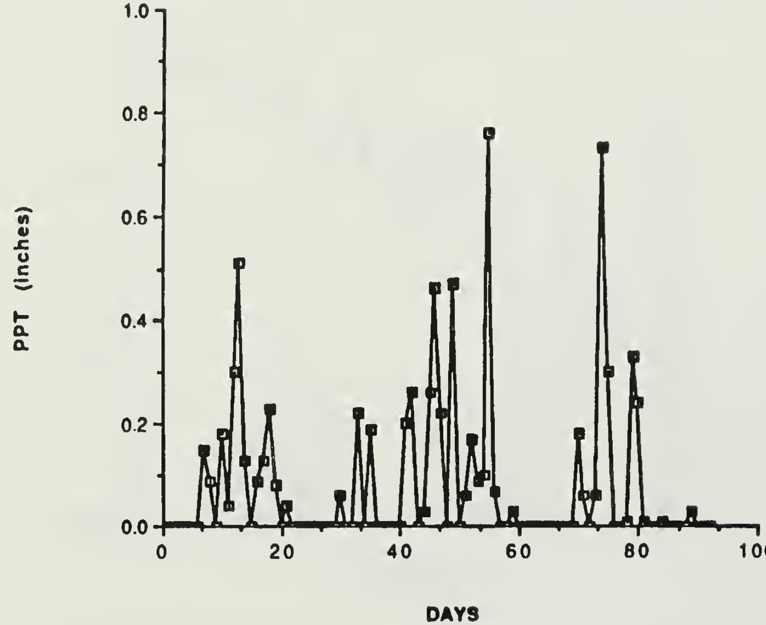


1960

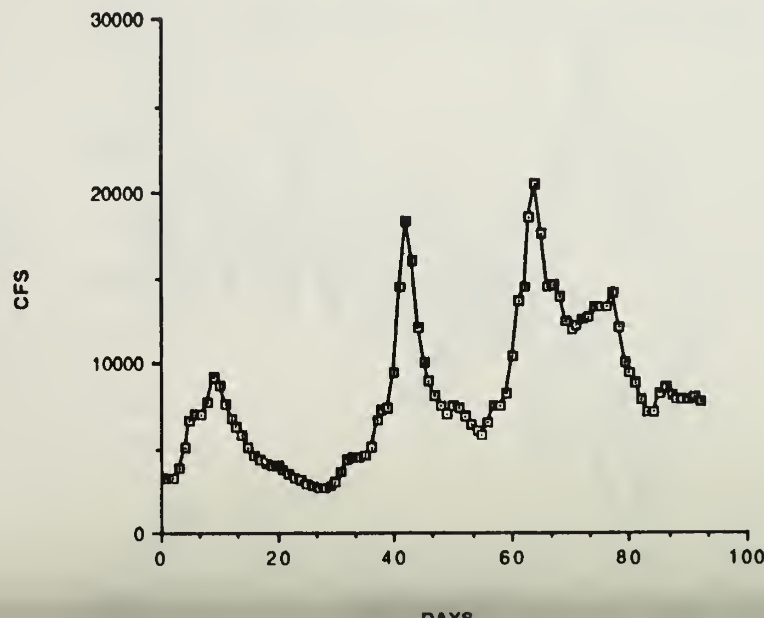
West Glacier



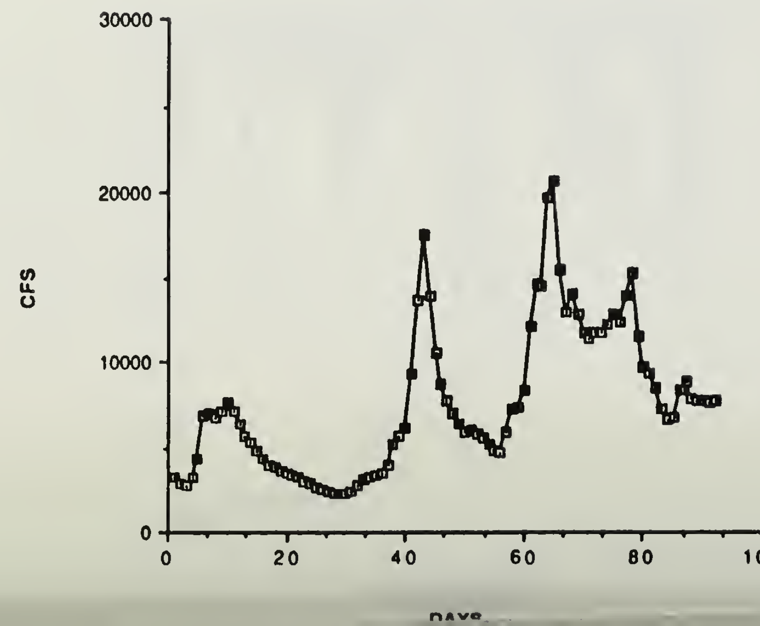
West Glacier



North Fork

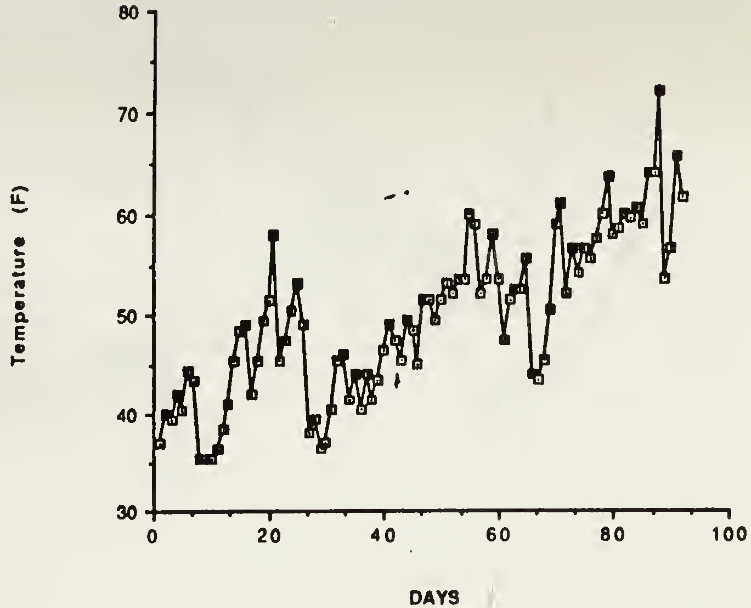


Middle Fork

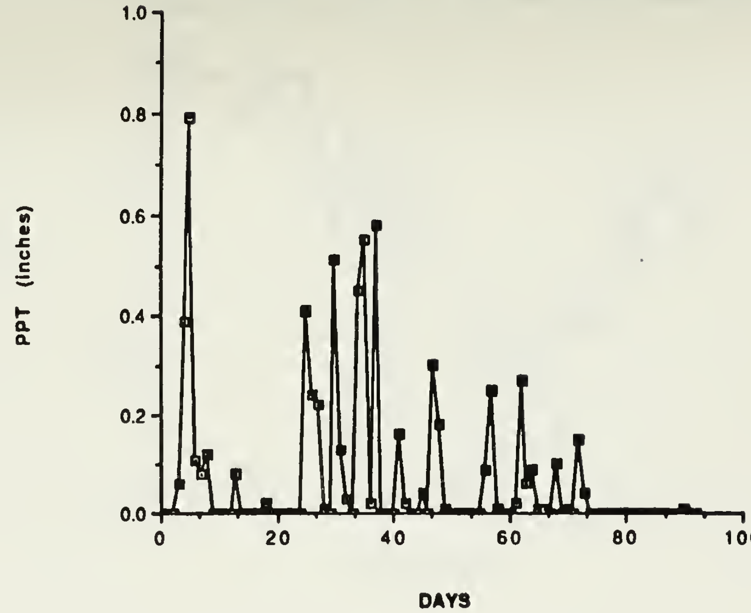


1962

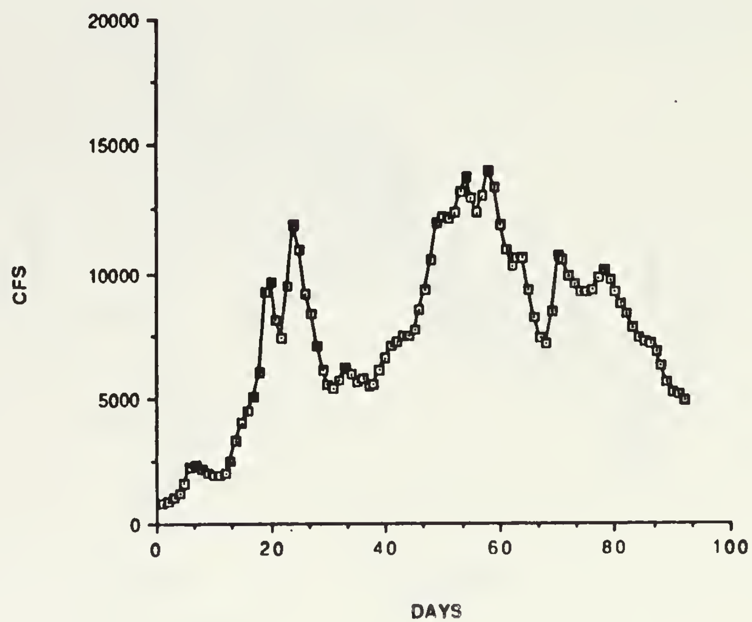
West Glacier



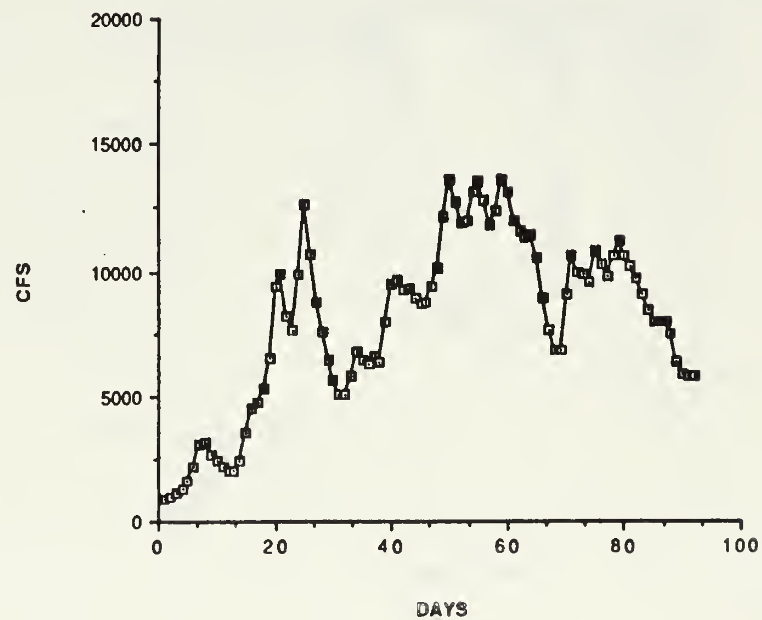
West Glacier



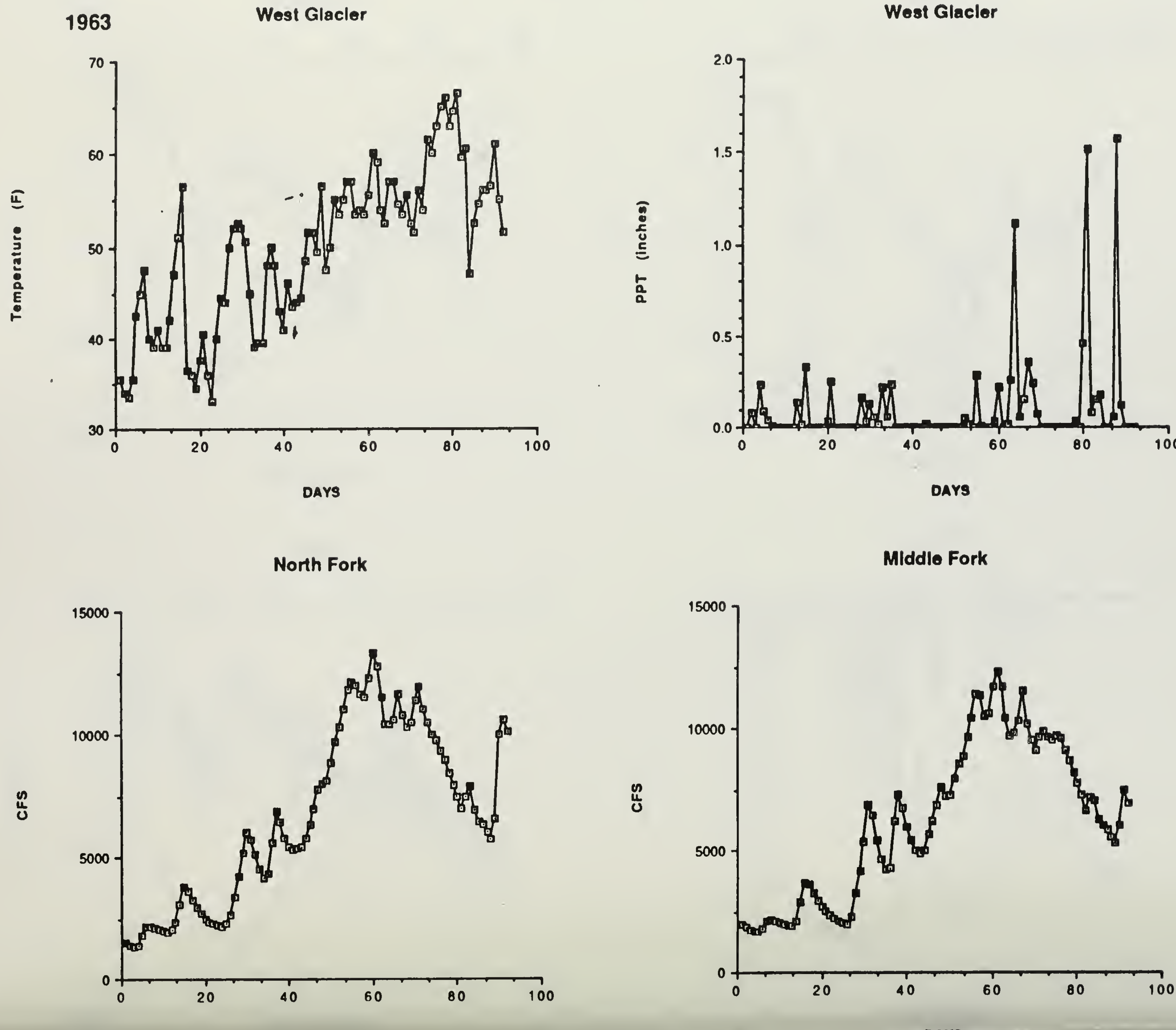
North Fork



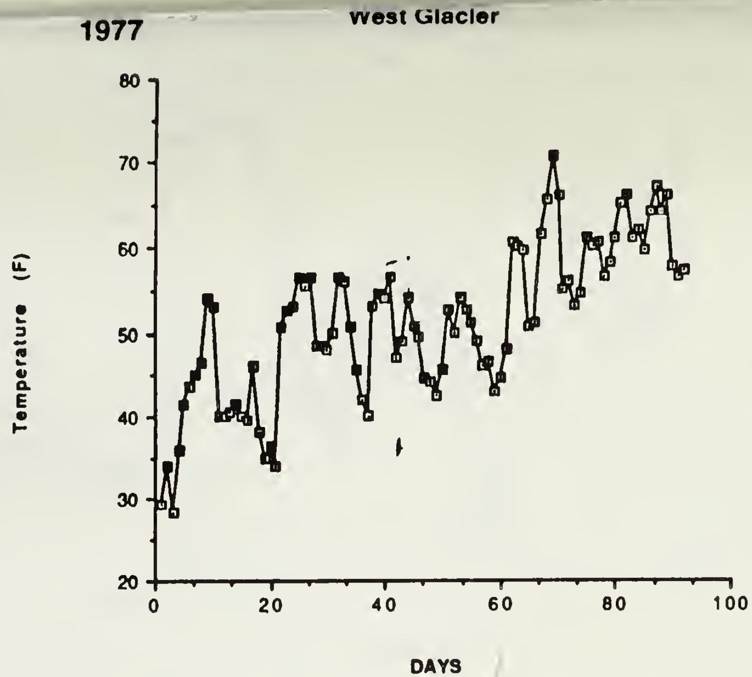
Middle Fork

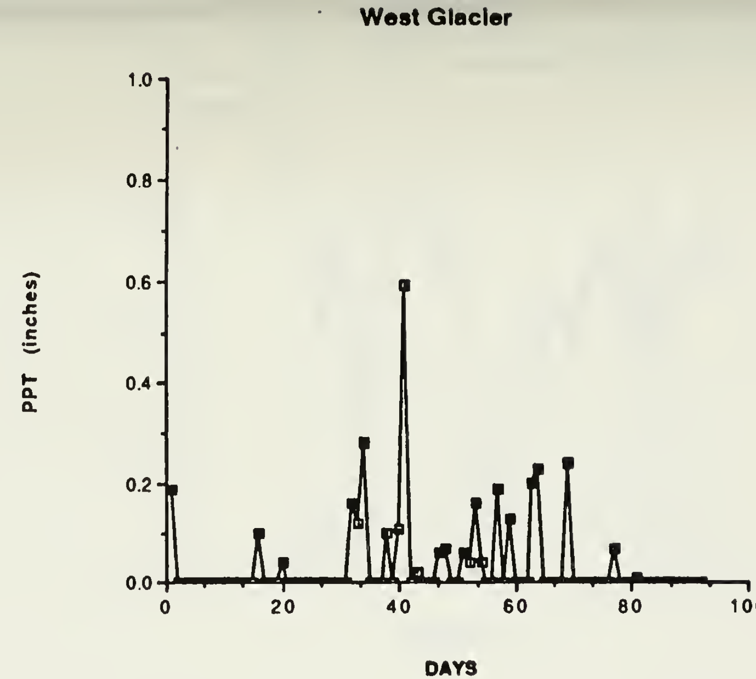


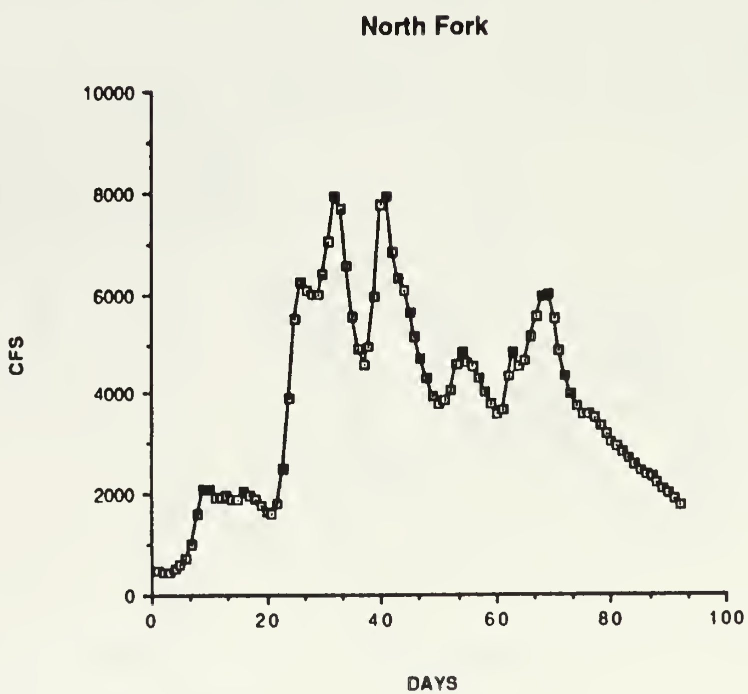
1963

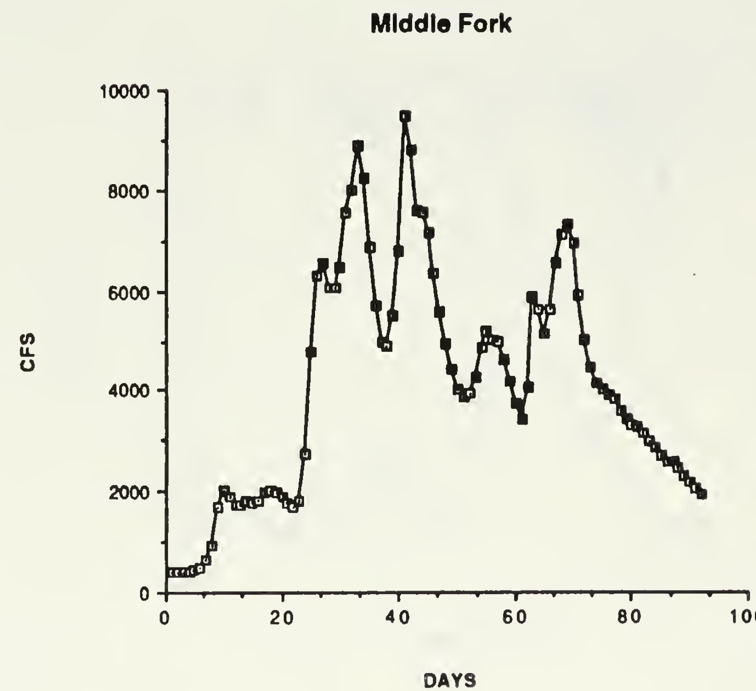

West Glacier
Temperature (F)
70
60
50
40
30
0
20
40
60
80
100
DAYS
West Glacier
PPT (inches)
2.0
1.5
1.0
0.5
0.0
DAYS
North Fork
CFS
15000
10000
5000
Middle Fork

1977


West Glacier
Temperature (F)
80
70
60
50
40
30
20
0
20
40
60
80
100
DAYS

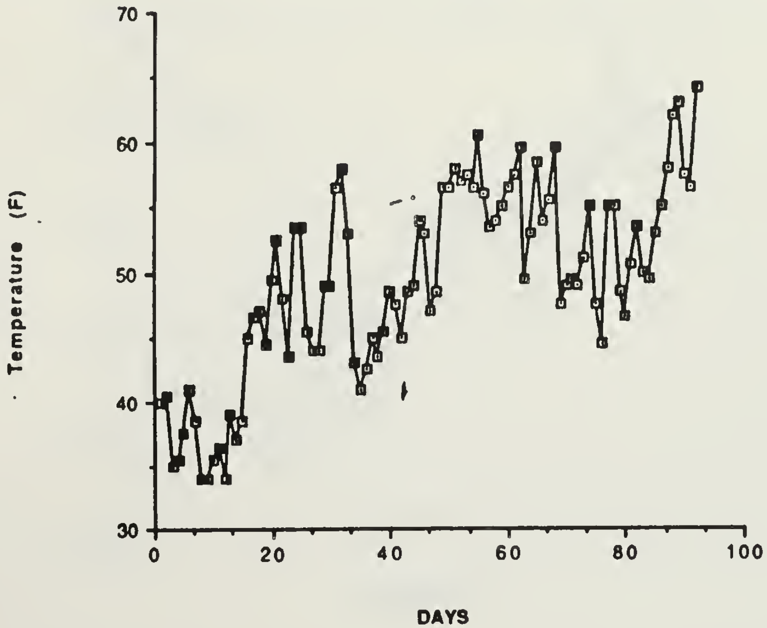

West Glacier
PPT (inches)
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
DAYS


North Fork
CFS
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
DAYS

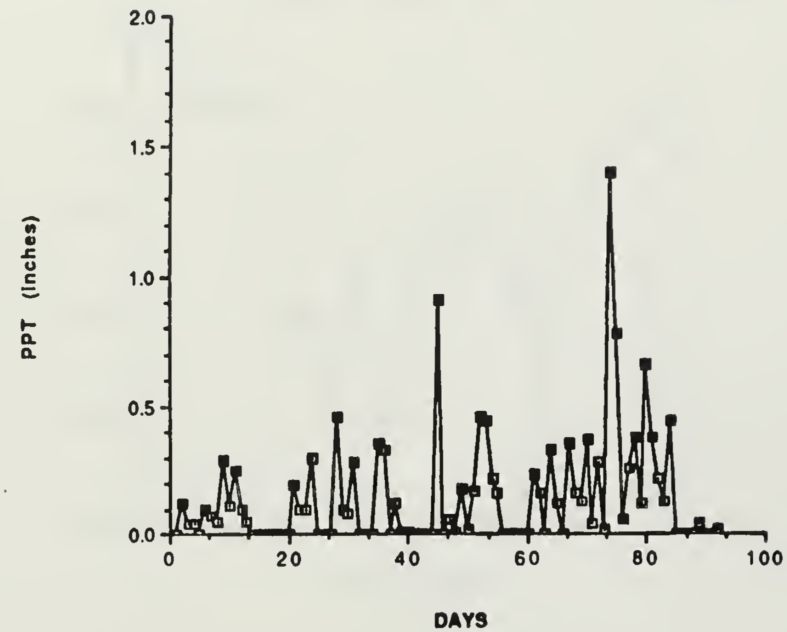

Middle Fork
CFS
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
DAYS

1981

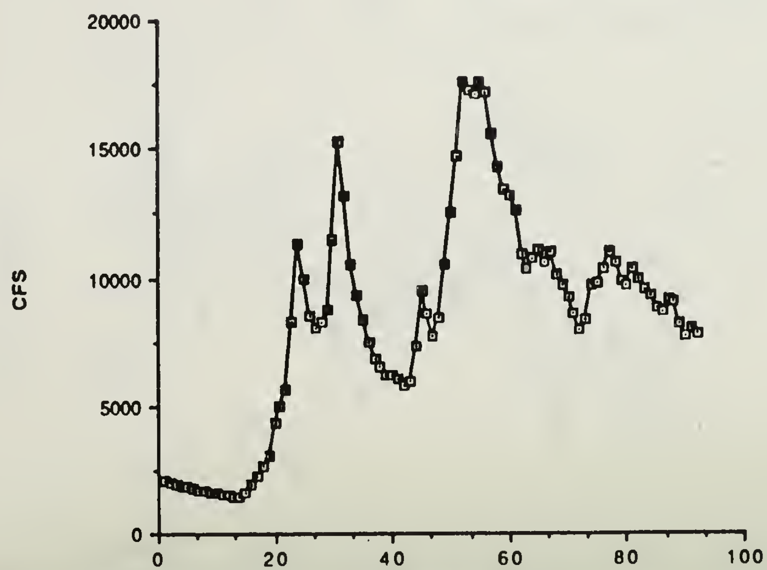
West Glacier



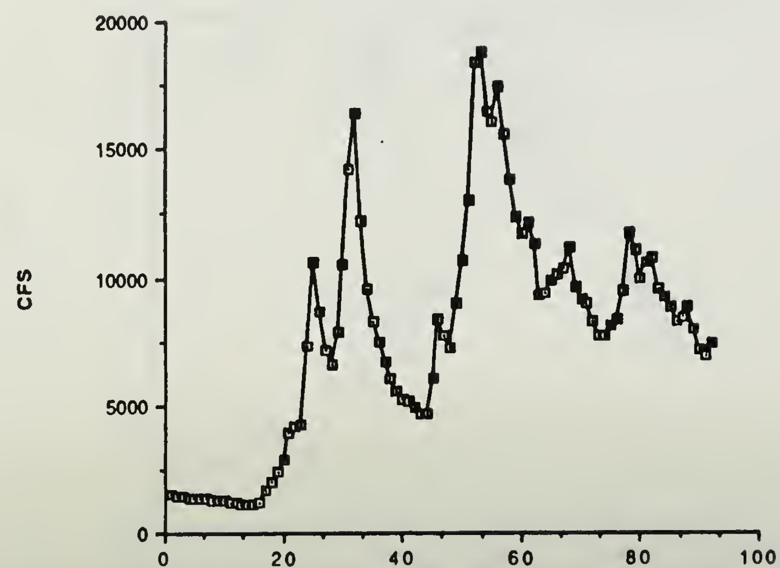
West Glacier



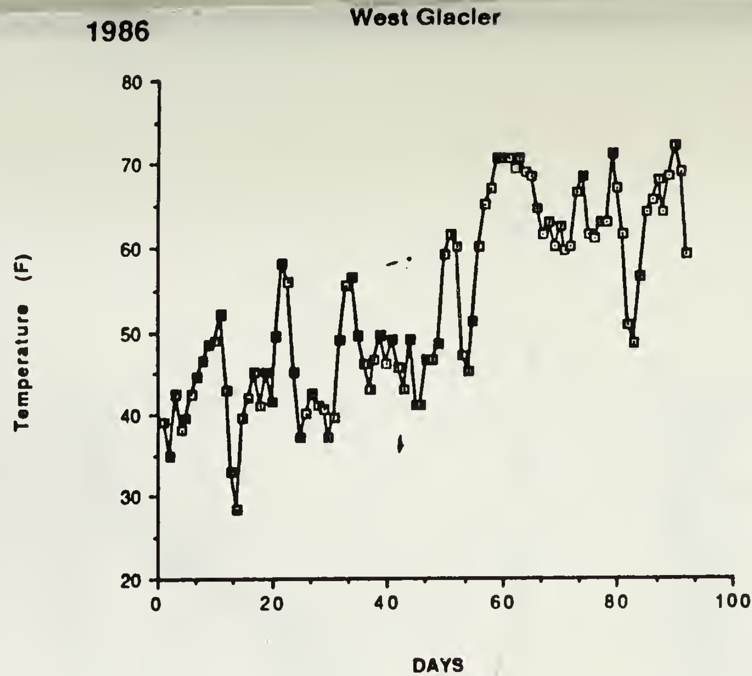
North Fork

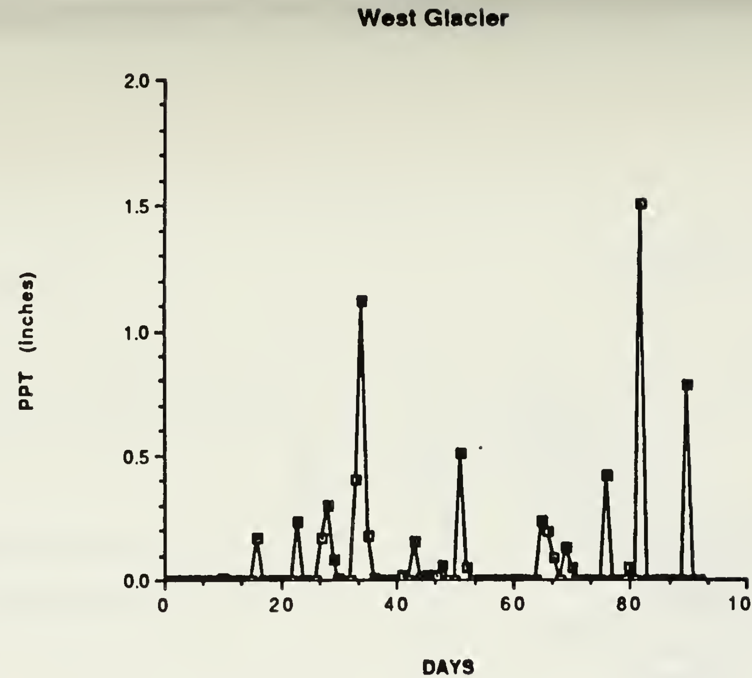


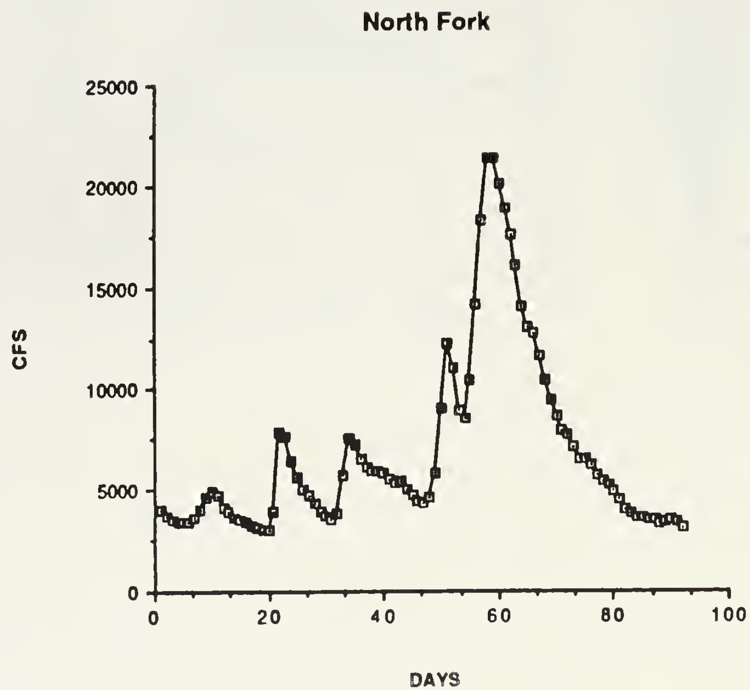
Middle Fork

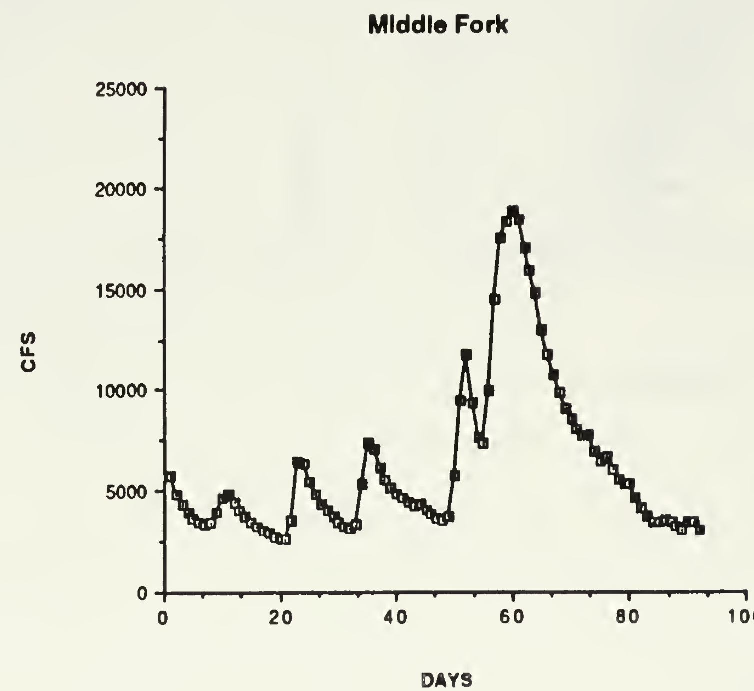


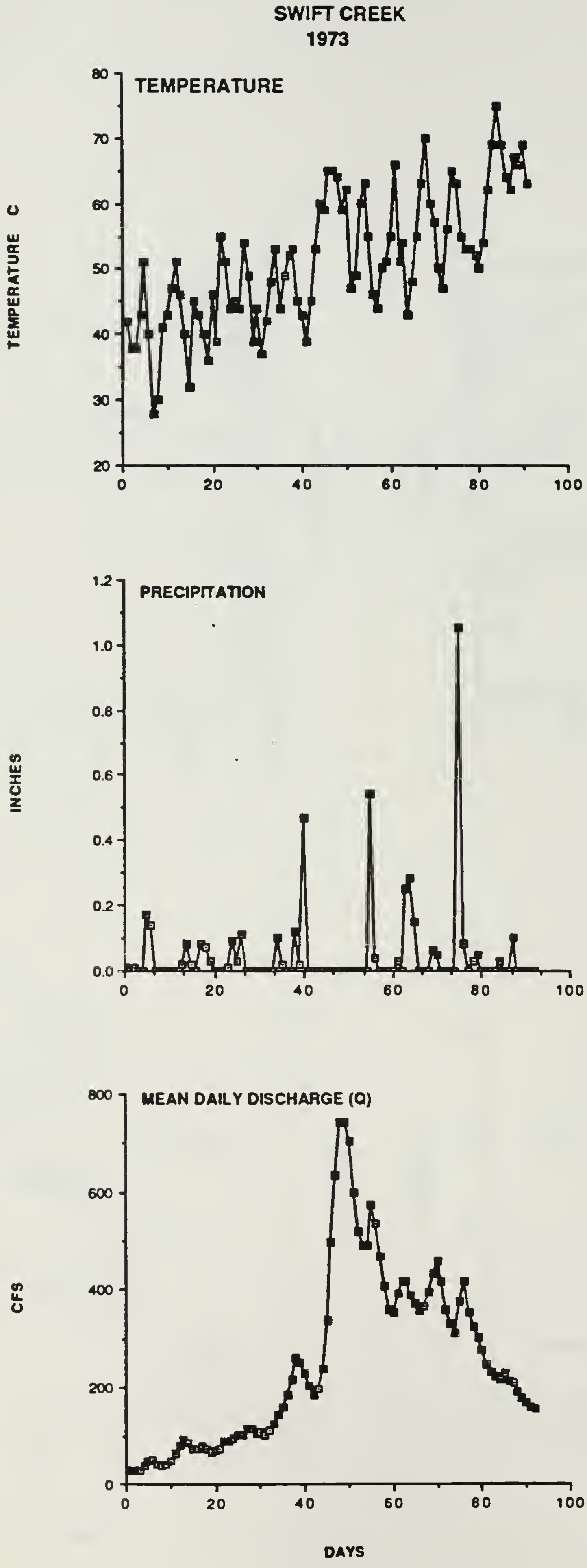
1986


West Glacier
Temperature (F)
80
70
60
50
40
30
20
0
20
40
60
80
100
DAYS

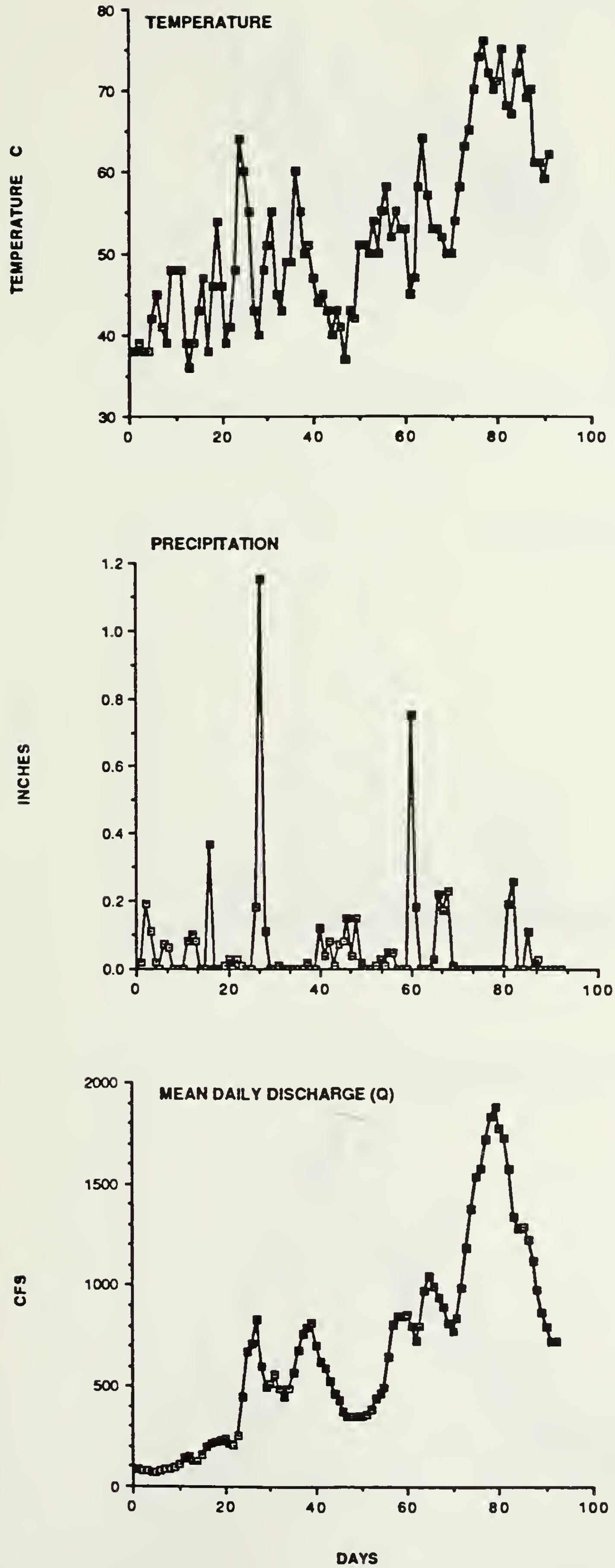

West Glacier
PPT (Inches)
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100
DAYS


North Fork
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS

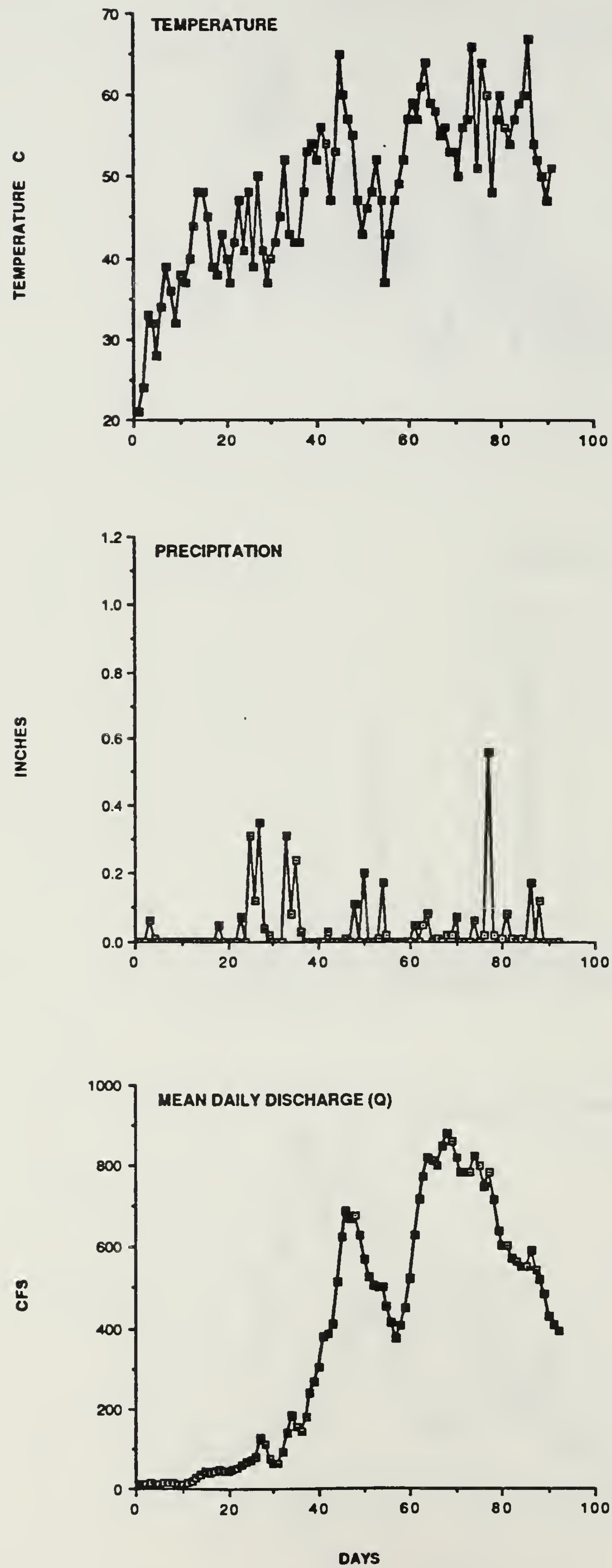

Middle Fork
CFS
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
DAYS


SWIFT CREEK
1973
TEMPERATURE
TEMPERATURE C
PRECIPITATION
INCHES
MEAN DAILY DISCHARGE (Q)
CFS
DAYS

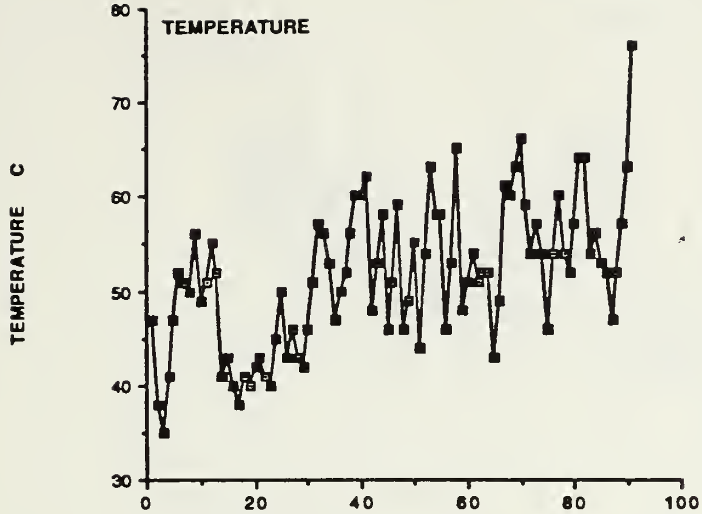
SWIFT CREEK
1974

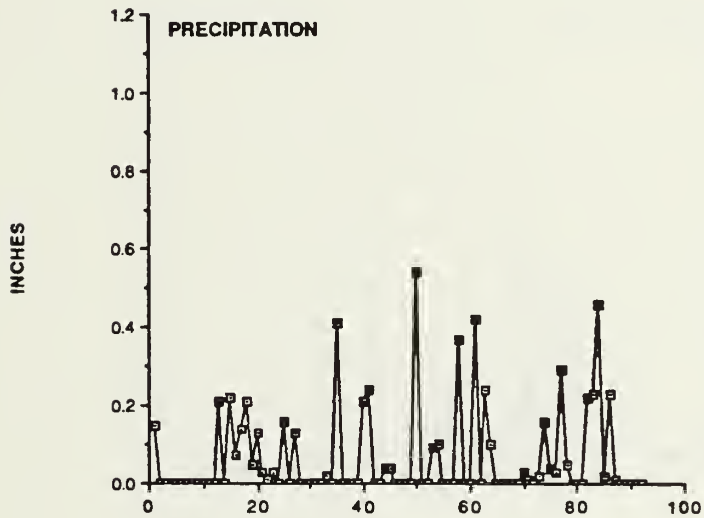


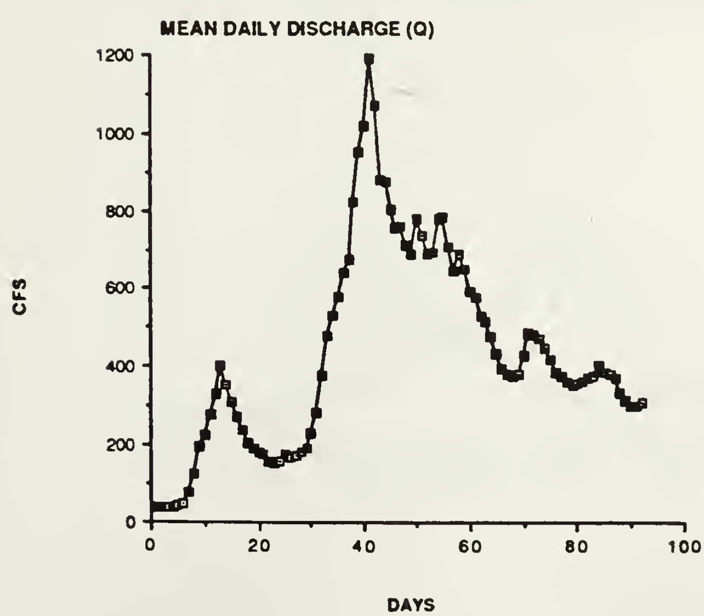
SWIFT CREEK
1975



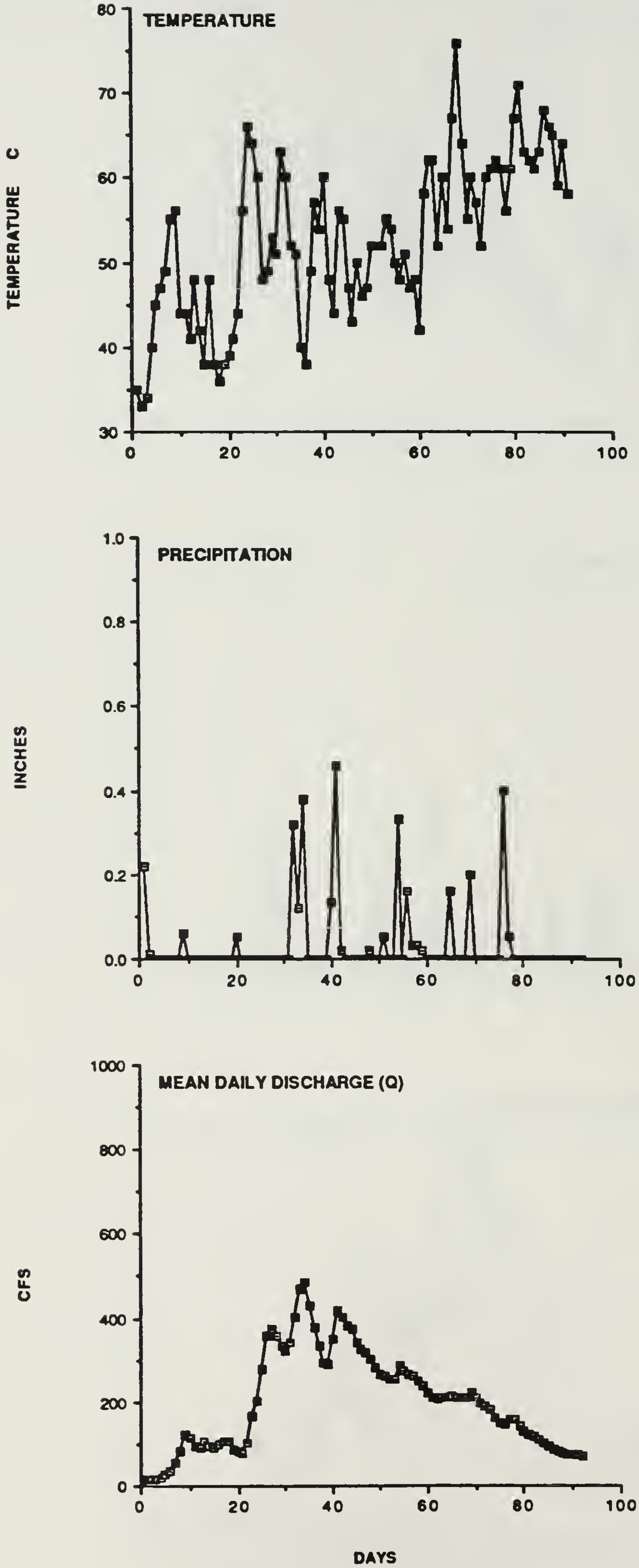
SWIFT CREEK
1976



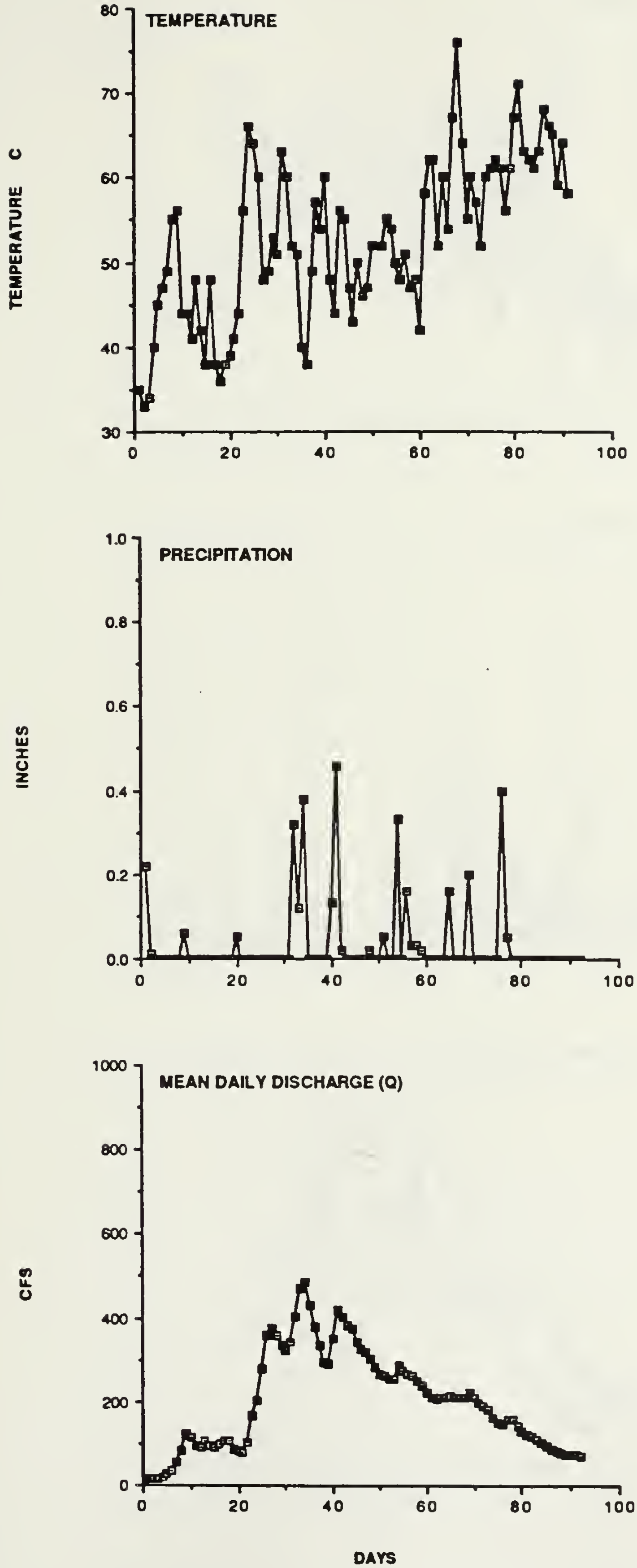




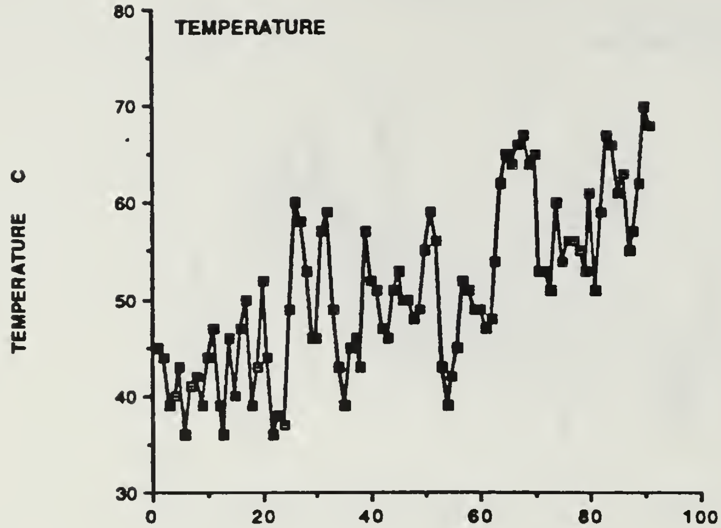
SWIFT CREEK
1977

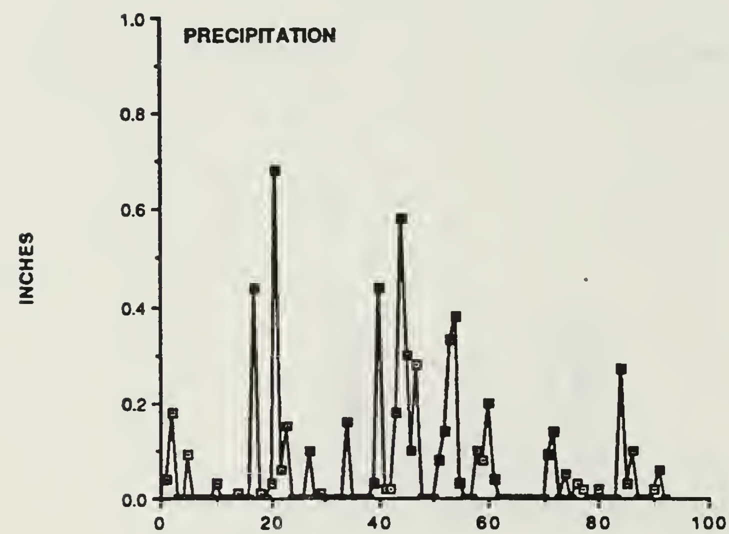


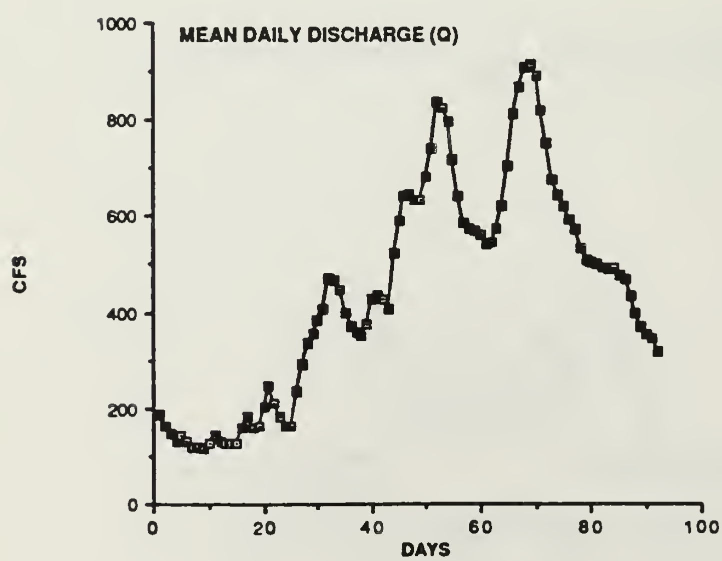
SWIFT CREEK
1977



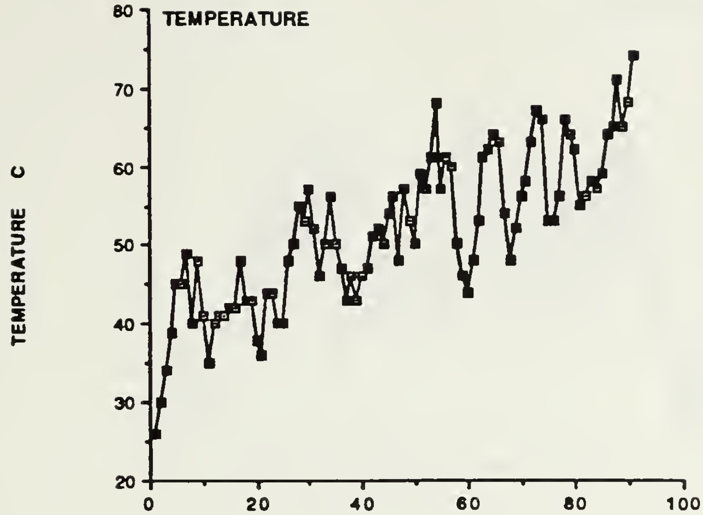
SWIFT CREEK
1978

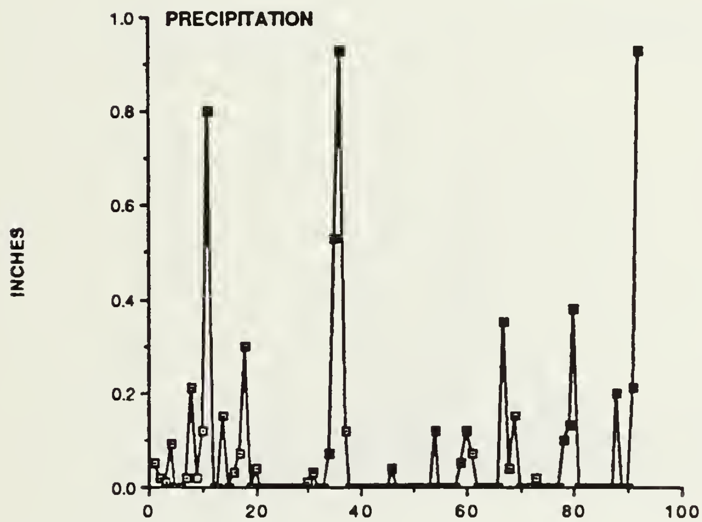


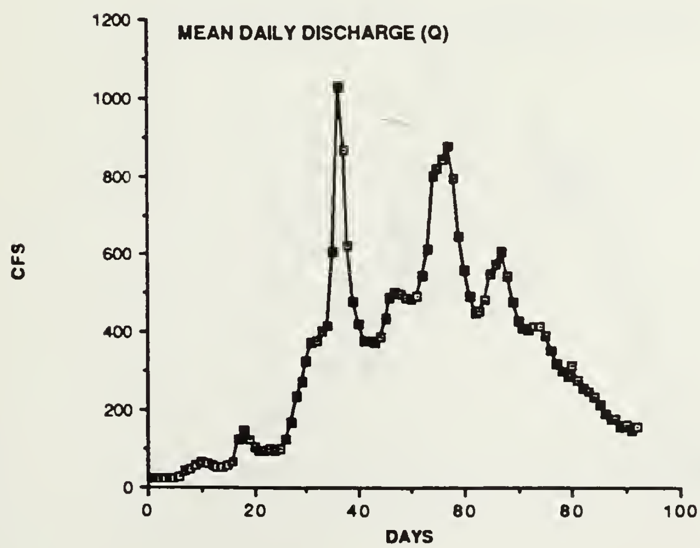




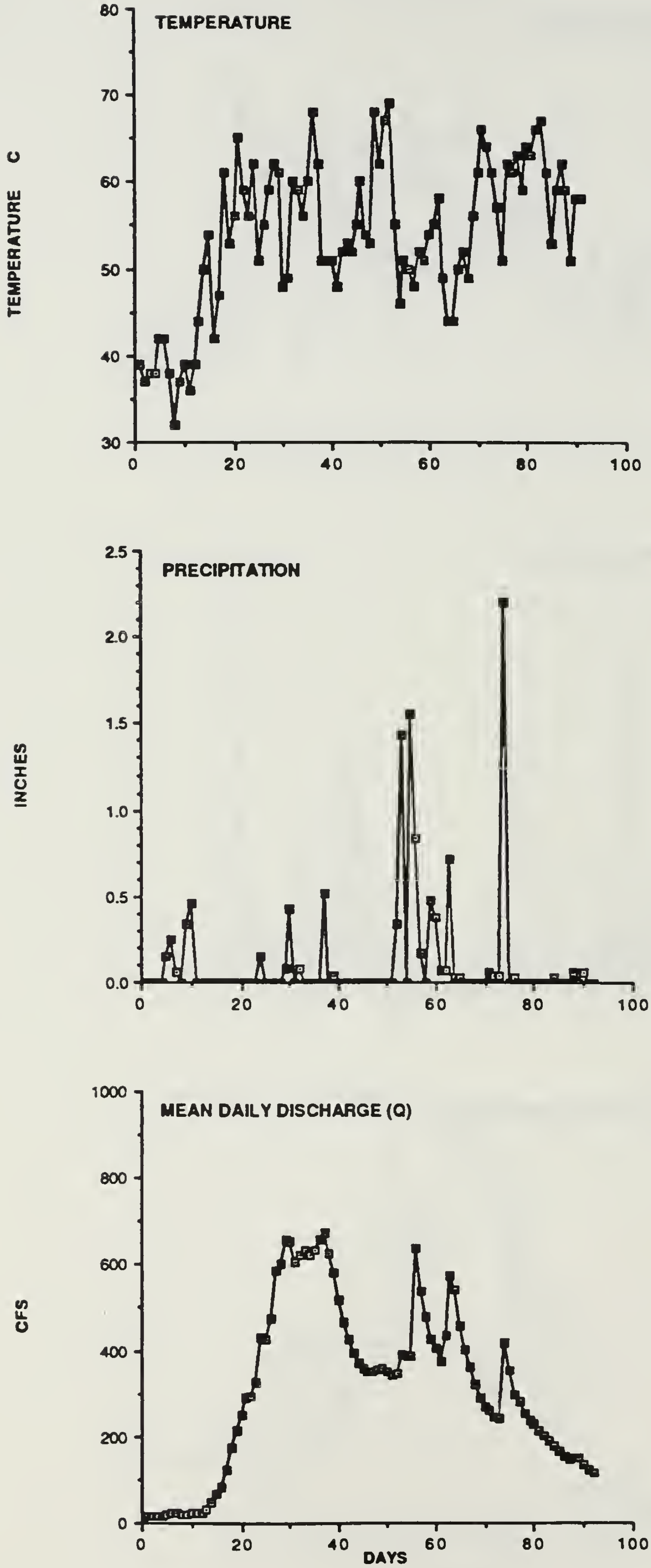
SWIFT CREEK
1979



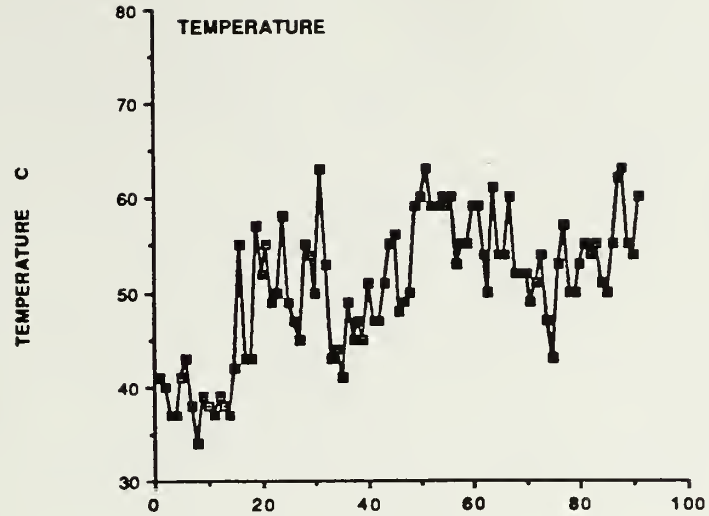


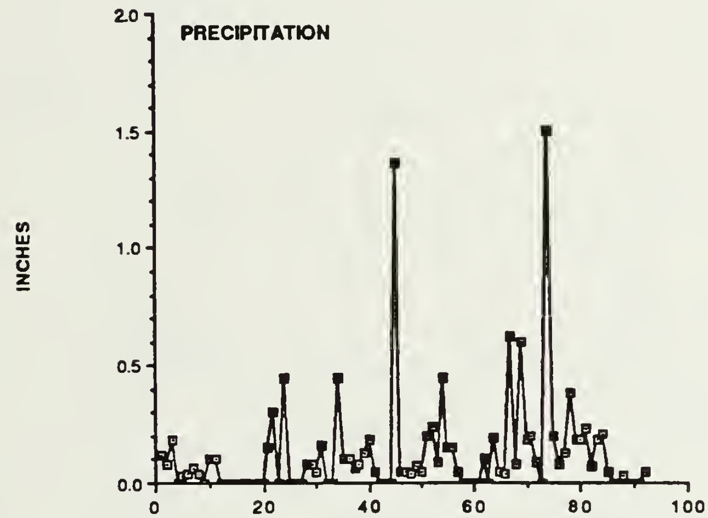


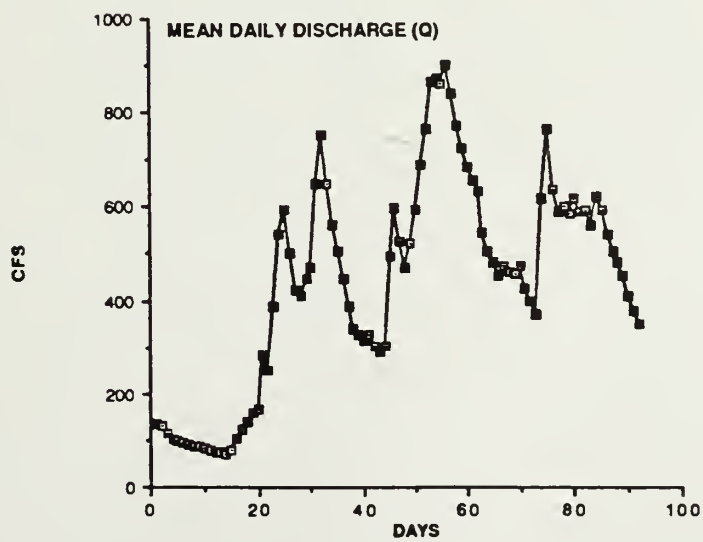
SWIFT CREEK
1980



SWIFT CREEK
1981







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